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COMPARISON OF EXPERT JUDGMENT METHODS USED FOR MODERNIZATION DECISION: THE CASE OF MIG-29

by

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The research includes analysis of the reasons, constraints and tendencies in the modern aircraft modernization process. Weapon modernization is usually driven by several objectives, all of them in one way or an another are pertinent to resource allocation. Reliable analytical tools are important to make good decision. Cost-effectiveness and cost utility approaches are evaluated.

Comparison of both methodologies is based on the MiG-29 modernization situational model. TASCFORM-AIR Model provides static indicators of military force potential. This can be viewed as measures of effectiveness. The LDW program computes the alternatives' utility by combining its measure levels based on the analyst's preferences. The results produced in both cases are useful in several ways. They are indicators, however indicators rather than "answers" to the decision making problem

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COMPARISON OF EXPERT JUDGMENT METHODS USED FOR MODERNIZATION DECISION: THE CASE OF MIG-29

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I. INTRODUCTION

A. BACKGROUND

There is no need to be an expert in aviation to notice a significant drop in the production and design of new combat aircraft at the present time in all leading countries. Among the main reasons for this, one can mention the end of the Cold War and the collapse of the Soviet Union; others will emphasize economic difficulties and the rapidly increasing costs for new aircraft design and production. The countries making new weapon platforms produce quantities of aircraft much less than the levels of the 70s and 80s.

The days when the United States and the Soviet Union produced a new class of combat aircraft every ten years and a new transport every fifteen years are gone. Procurement of new military aircraft now is more a political and economic issue than purely military. In addition, the life cycle cost of the whole system plays as important a role in source selection as combat characteristics.

Nevertheless all military doctrines and recent combat experience show the increasing role of aviation in the structure of military forces. For the military economist, it means that to keep old aircraft safe and able to perform modern operational tasks require some additional money. In those conditions many countries have chosen the upgrade and modernization path. Many studies show that most jet combat aircraft of the so-called "third generation" have great potential for modernization and upgrade using

modern technology. Even aircraft veterans, such as the MiG-21 and the F-5, will get new life, and the description of the modernization programs for MiG-29 and F-15 have appeared in all specialized magazines.

In many cases, industry, trying to find new markets, proposes its own programs to customers. But generally, aircraft upgrade programs tend to be customer driven, with industry responding with a solution tailored to specific customer requirements. On the other hand, a number of pitfalls exist on this path. Two basic conditions have vital importance for any aircraft upgrade plans. First, the basic airframe must have an acceptable future service life and, second, ensuring an adequate holding of basic spare parts is important.

The aircraft built before 1970 had service lives of 15-20 years. Later, the electronic component of the aircraft became increasingly important, and in recent models designers have pre-planned the mid-life upgrade. Today, the cost of the frame and the engines are probably less than 50% of the total aircraft cost, and aircraft such as "Eurofighter" have built-in upgradeability from the start that allows the full potential of the upgrading to be realized.

Clearly, upgrading and modernizing are only a partial solution. Future needs will demand replacing old machines with new ones. Even the best modernization program is not a panacea for new procurement, but modernization can buy the user time to consider the alternatives. Modernization can be a direct replacement by buying a new generation of the same class of aircraft, or it can be indirect, by giving an aircraft a new role. Modernization " can reduce cost-of-ownership for the later part of an extended service

life, and it can offer interim capability until the next generation comes along or an improvement is made in an existing role. The decision to upgrade lies with the user alone." (Gething p. 2)

The never-ending researches of designers and producers of the aircraft, engines, equipment and armament increase the number of alternatives available. What combination to chose? Which characteristics are more important? Having constrained budgets, military planners often face complicated decision problems with great uncertainties and multiple inputs and outputs. Good intuition and rich experience are not sufficient to reach the best solution. Modern economic and military sciences offer a great number of analytical instruments for decision making and support. Which one best fits a modernization decision?

In my thesis I will evaluate widely used scientific analytical methodologies as to their practical use by military managers for modernization decision-making.

B. PURPOSE

By considering the vital role of research tools for effective allocation of budgetary recourses, I will evaluate selected methods, approaches, and real programs for decision-making in aircraft upgrade and modernization.

The main purpose of this thesis is to estimate data, examine assumptions and evaluate the results of different methods and to make recommendations for their practical use within the Armament Department of the Ukrainian Ministry of Defense. The case of

the MiG-29 modernization will be used to evaluate research tools and to illustrate recommended methodology.

C. RESEARCH QUESTIONS

The research questions due to the nature of the problem, and because of the use of situational modeling for methodology evaluation are divided into two groups.

Group I. Pre-modeling questions:

- What are the main reasons for combat aircraft modernization and what are the objectives and the constraints on modernization?
- What generalization and assumptions can be made in modernization modeling?
- How can cost-effectiveness and cost-utility analysis be used for modernization decision-making?
- What specialized and universal decision support programs and software exist?

Group II. Post-modeling questions:

- What criteria can be used for methodology selection?
- What are the key dimensions of the methodology selection problem?
- What are the main measurement-scale selection and construction issues relevant to given multi-attribute-utility analysis?
- What are the advantages and disadvantages of assessed methodologies?

II. AIRCRAFT MODERNIZATION DECISION

The improvement or replacement of military weapons system is generally referred to as weapon modernization. The ostensible purpose of such modernization is to correct shortcomings in the original weapons, or respond to either changes in the weapons purpose or to changes in enemy weapons. (Sorenson, p. 23)

There are three ways to modernize existing weapons. Modern aircraft as a system can be improved:

- as a platform (speed, maneuverability, range).
- as a part of strike complex (command control, communication and navigation).
- as a weapon (power, accuracy, effectiveness).

Modernization may change just a single element of a weapon system or it can be a part of state weapon program. For example, the latest modification of the F-16 after a midlife upgrade is believed to be two or three times more effective that its predecessor. (Sweetman, p. 26)

Technologically speaking, modernization can be as evolutionary as the case of the MiG-21 that was gradually transformed many times during its 45-year history, or as revolutionary as when one technology is completely replaced by another. For example, the transformation from piston to jet engines in aviation was clearly revolutionary.

Technology can influence not only changes in weapons, but can also transform war itself. In this Chapter, I will evaluate modernization as a subject of policy that can impact the defense resource allocation.

A. REASONS AND OBJECTIVES

Weapon modernization is usually driven by several objectives, all of them in one or other way are pertinent to resource allocation. Modernization can result from national security requirements or particular service demands based on strategy development. In a political context, it can arise from regional or group interests. Analyzing military aviation development we can define how the following typologies explain weapon modernization:

- Modernization due to strategic necessity. National security defines threats and then strategy produces weapon performance demands;
- Weapon modernization based on demand to match a new military capability of a rival nation;
- Modernization based on interest of powerful domestic groups that benefited from military founding;
- Weapon modernization as a means to maintain a defense industrial base;
- Modernization opportunities based on scientific and technological innovations;
- Modernization as the result of shifted control over the military acquisition process.

We can separate these reasons on two levels: *strategic* (the first two) and *structural* (the others). The first group is connected to the international environment as the stimulus for weapon development; the second group focuses on domestic policies.

To better understand the modernization decision making process, I'll evaluate separately the influence of state strategy and military competition, the role of military doctrine and the place of modernization within the military planning. To make this

analysis more relevant to methodology selection, I will evaluate the technical level of modernization caused by flight safety, effectiveness and obsolescence. Even though technical problems are partly included in strategic and structural levels, evaluating them separately is reasonable in the context of this thesis.

1. Strategy and Doctrine

Strategy connotes the linkage between national political objectives through the threat or use of the military forces. (Sorenson, p. 26) For example, for the United States, the Cold War strategy was a combination of deterrence and containment. Both were based on the expectation of expanding Soviet power and on the belief that military force was an appropriate policy instrument for containing Soviet expansion. One doctrine that was selected to support these strategic objectives was the employment of Air Power. However, the strategic environment has changed. William Cohen in his Testimony before the Senate Armed Services Committee on February 5, 1998 said, " The future conflict environment will present challenges that are dramatically different from those confronted by our armed forces during the Cold War and even the Persian Gulf War. Consequently our current concept of tactical air forces will likely have to change dramatically."

Presently, the strategy involves minimizing serial production runs of new aircraft under all but two circumstances: first, when the new system offers a major boost in military effectiveness that solves a major strategic or operational problem, and second, when existing systems have reached the end of their useful lives.

Doctrine refers to the operating principles of an organization that link weapon application to a specific end. Doctrine translates the generalities of strategy to operating principles. For example the Air Force Modernization Planning Process (AFMPP) is part of the Air Power doctrine and the mechanism for supporting the five core competencies-air superiority, space superiority, precision employment, global mobility and information dominance. The AFMPP integrates the elements that provide the foundation for the five competencies into a coherent modernization plan that reaches 25 years into the future. The foundation elements included in the modernization plan are:

- readiness and sustainment;
- research, development, test and evaluation;
- logistics;
- information technology;
- equipment and facilities;
- manpower.

However, replacement of aircraft has slowed significantly in recent years because of budget constraints and affordability. The result has been a shift to increased upgrading and life extension of many systems beyond what was typically done in the past. (Butowski, p. 3)

In an ideal world, *strategy* and *doctrine* ought to provide directions for persons who are in charge of design and procurement of weapon. But strategy and doctrine are abstractions, which do not translate easily into the precise requirements for weapons. So, there are other reasons that can explain aircraft modernization choice.

2. Readiness and Effectiveness

One of the earliest paradigms in the literature of social science is the arms race typology. This view to modernization was originally devised by Lewis Fry Richardson who developed models of arm acquisition with the hope that understanding the process might help in preventing war. (Sorenson, p. 39) The fundamental assumption behind arms race models is that two hostile nations will arm themselves completely, with one nation stimulating the arming of the second in a reciprocal fashion. Arm races are thus "action-reaction behaviors," with each nation trying either to win the arms race at best or at least is trying to avoid losing it. Nations as a result, arm themselves for external reasons, reacting to a perceived threat.

Strategic and structural categories of arms races influence the technical level of the modernization process, through the demands of military readiness and individual or group effectiveness. Joint Pub 1-02 defines readiness as "the ability of forces, units, weapon systems or equipment to deliver the outputs for which they were designed (includes the ability to deploy and employ without unacceptable delays)."

As technical element of modernization, readiness and effectiveness have time, range, loading and accuracy components. For example Russia's program of tactical aviation development will include the following directions: prolongation of the service time, modernization and improvement of the currently used fighters and missile armament to broaden their ability to destroy both the aerial and ground targets, and improving of range and autonomy. The next direction is standardization of the fighter

aviation units training within the framework of Air Force and Air Defense formations to provide both air defense and battlefield support. (Butowski, p. 7)

The essential aims of Russia's Air Force modernization are as follows:

- an increase in combat effectiveness, practically due to the application of new weapons previously prepared for the next generation aircraft;
- a multi-role capability in combat aircraft obtained through the use of new fire control and weapon systems;
- an enhanced night and adverse weather mission capability;
- an expansion of the "information field" for aircrew through the use of new navigation systems, data links, etc; and
- a reduction in maintenance cost during the prolonged service life of aircraft by replacing standard maintenance schemes with maintenance according to the actual technical conditions of aircraft.

The results of modernization in Russia are characterized by the growth of the integral parameters, such as the coefficient of the combat potential while attacking the aerial or ground targets. The Mikoyan design bureau representatives presenting MiG-29SMT program tell that modernized MiG-29 combat efficiency in an air-to-air role will be 2.1 : 1 compared with the current MiG-29 (and even 6.5 : 1 in long distance air combat). The combat potential of the aircraft in air to ground mission will supposedly be increased by a factor of 3.8 , or even 8 against point targets. (Polushkin, p. 6)

3. Flight Safety

Flight safety has a special position among the reasons and objectives of modernization. It is only one indisputable reason because of the value of the pilot's life,

and threat of losing highly expensive weapons due to technical problems make the military and the producers cooperate to improve safety and reliability.

When flight safety design flaws are discovered, the consequence is usually the suspension of operations. Designers and producers use all their resources to eliminate or to neutralize possible threats. If flight restrictions don't correct a flight hazard, the design bureau has to make structural changes in the shortest possible time. This has been labeled the so-called "urgent modernization."

Another level of modernization relevant to flight safety is pre-planned or preventive upgrade. Employment of aircraft reveals many weak or problematic areas. Sometime they are not urgent or occur infrequently. Analyzing defects and malfunctions at the aircraft design bureaus creates upgrade programs for regimental and depot levels of maintenance. The regimental specialists usually change specific details and elements, while depot personnel traditionally make structural changes. Producer specialists or even design engineers can make highly complex upgrade and modifications.

Soviet era statistics show that for tactical aircraft, such as the MiG-25PD, the number of elements to be upgraded would generally total 10 to 15 after each 1500 flight hours. At the same time, from 1980 to 1988 flights of MiG-25's were suspended six times and flights were restricted until structural changes were made more than 15 times. The cost of a safety related modernization might represent from 8 to 10 % of the lifetime aircraft maintenance cost.

4. Obsolescence

Examples of modernization mainly caused by obsolescence are the Soviet MiG-21 and the American F-5 upgrade programs. These also are examples of modernization that were created to satisfy customer needs. Countries, such as Romania, Egypt, Turkey and Taiwan, which possess these aircraft do not have sufficient funds to buy new or even used aircraft and have to use available airframes. In both cases, design bureaus agreed that these aircraft are still in good condition and their useful lifetime can be prolonged for 10 to 15 more years. Another reason these countries can employ these used aircraft is that the air industry has created a lot of universal systems and elements that can be easily adapted to any airplane. Examples are the Global Position System (GPS) navigation, radar and universal weapon delivery systems. On the other hand air forces of many countries have numerous special tasks (patrolling, training, counter terrorists operations and so on) that allow using aircraft with comparably low performance. So, the primary problem is the obsolescence of existing armament and equipment. From material published in aviation journals, we know that in both cases (MiG-21 and F-5) objects of modernization are cockpit equipment, navigation, communication, radar and armament.

The advantage of such modernization is a high level of cost effectiveness index. For example the cost of the MiG-21-98 upgrade program is about 30% of an aircraft's initial cost in constant rubles, and the estimated increase of effectiveness is from 1.7 to 2.5. The problem is that the technological and information revolution dramatically increases "the depreciation rate" of new equipment and weapon systems and as a result the comparative effectiveness of old aircraft may be worse than predicted.

B. CONSTRAINTS

1. Technical and Technological

There are two fundamental requirements to be fulfilled before any aircraft can be upgraded or new equipment can be installed. First and foremost, the basic airframe must be sound with an acceptable service life remaining. The airframe structure can deteriorate depending on the nature of its use and the level of maintenance it has received.

Second, if the airframe is in good condition and well maintained, before proceeding with the upgrade, it is important to ensure an adequate availability of basic spare parts. If the storage of spare parts is sparse, it is necessary to estimate the possibility of ordering parts from the original or side producer. Both options could be expensive and could significantly increase maintenance cost.

One more important issue at the present time is the movement from analog to digital electronic systems. For old aircraft, a partial upgrade can create two incompatible electronic systems.

The next problem is adapting new weapons to the airframe. Sometimes the weight of additional frame elements to adjust to the new weapon to an old aircraft may be higher than the weight of the additional weapon itself. This increase in weight might lead to another problem: insufficient power. Of course, experience also suggests that many systems could be lighter than the ones they replace. However, aircraft generally gain weight during upgrades, even if this is in the form of additional weapons-carrying capability. Obviously, ascertaining whether the engine(s) will have sufficient power to

deliver an equal or better thrust-to-weight ratio in the upgraded aircraft is important. (Gething, p. 5.)

There are several arguments concerning how technology influences modernization. On the one hand strategy and doctrine may guide the technology of weapon development, stimulating technology. On the other hand, it has also been argued that technology itself simulates and constrains the development of strategy, since technological development can make new strategies possible. Yet another argument is that technology reduces uncertainty and its use may be maximized without specific knowledge about the present or future state of adversary capability. New technology is sometimes developed independently from weapon projects, but then incorporated into them because it is available.

2. Finance

> *In the year 2054, the entire defense budget will purchase just one aircraft. This aircraft will have to be shared by the Air Force and the Navy 3.5 days each per week except for leap year, when it will be made available to the Marines for the extra day.*
>
> *Norman R. Augustine*

As economic difficulties impact a world already wrestling with reduced defense budgets, the hard fact is that fewer new weapons platforms are being developed. Yet it is not only the budgetary impact that is decreasing this development. The state's military budget expands all security problems including strategy and force structure.

Balancing fiscal constraints against mission requirements is a relatively new problem for military planners in the former Soviet republics. New democratic processes

dictate that the military compete for funding along with the other needs of the nation. In the 1980s the Soviet Union spent about 20% of the GNP on the military, while the Ukraine presently can spend only 2% of the GNP. Money available for military programs is significantly different from that ones available ten years ago, and so are possibilities of military industry. We can expect this state of affairs to continue in the future.

Even so, after the Gulf War and the Serbia conflict the world was convinced of the importance of air power in the modern conflicts; however, any nation can spend only a reasonable amount of money for defense. The age-old question of "How much is enough?" will surely continue.

As we look at the cost of modernization, high technology has an attractive lure. Technology offers high military efficiency, stability and economy. But at some point in the development of a weapon system, the additional cost of increased capability outweighs the gains.

3. Scientific and Industrial Base

When analyzing particular aircraft modernization programs, it is easy to say that the main role in definition of such a program belongs to the original design bureau and manufacturer. Two scenarios are possible. First is the modernization of domestic aircraft, when all stages of an aircraft lifecycle belong to country-owner. This is the simplest case and this modernization is usually constrained only by a lack of money or technology. Second is when the owner bought or inherited aircraft without previously agreed

modernization. In this situation, modernization is also strongly constrained by the relations with the designer and manufacturer.

Even if the country has a modern scientific and industrial base, it can't modernize significantly without cooperating with the design bureau. The design bureau owns the technical information concerning the particular aircraft, and foreign customers might select only those programs proposed by a designer, or they might order a new project. Such an upgrade program may require much more money and time.

The design bureau is best qualified to estimate the lifetime for the frame and elements. It studies possibilities to change systems and armament and finally produces an upgrade program. Examples of the MiG-21 and MiG-29 modernization show that the initial intentions of some nations, even those with modern air industry, to undertake their own modernization finally led to a close cooperation with the original designer. The main reason for the design bureau's leadership is that it possesses full technological and construction documentation. Any changes made by another firm may weaken the design or introduce incompatible elements in operation. If uncoordinated changes are made, the design bureau can deny any responsibility for future flight safety.

Another constraining factor for countries that cannot produce their own aircraft is an insufficient industrial base for providing an upgrade. For example, all Warsaw pact countries inherited air depots able to provide high quality maintenance and repairs. Depending upon the level of design changes, modernization can be made by a depot (as in the case of the MAPO- DASSO program for MiG-29) or by a main plant (as in the case of the MiG-29SMT modernization). Clearly, modernization conducted by a

domestic depot is cheaper and gives additional advantages, such as professional repair personnel and the relative independence from manufacturer in future aircraft maintenance.

C. DECISION MAKING METHODOLOGIES

What makes decisions hard? Certainly different programs may involve unique difficulties. For example, any modernization decision requires us to think about the interests of various groups, as well as to consider the limitations of information on the inputs and outputs. Although every decision may have its own special problems, there are four basic sources of difficulty. (Clemen, p. 2) First, a decision can be hard simply because of its complexity. In case of modernization, an Air Forces must consider many individual issues: prices, effectiveness, lifetime, industry base, etc. Second, a decision can be difficult because of the inherent uncertainty in the situation. Third, a decision-maker may be interested in working toward multiple objectives, even though progress in one direction may impede progress in others. Finally, a problem may be difficult if different perspectives lead to different conclusions. Or, even from a single prospective, a slight change in certain inputs may lead to different choices. Different individuals may look at the problem from different prospective, or they may disagree on the uncertainty or value of the different outcomes.

So, which methodologies exist to help us make a decision? They are legion. Different schools, approaches and theories give us a large selection of scientific methods for decision making and support. The military planners use four main groups of

methods: benefit-cost, cost-effectiveness, cost-utility analysis and dynamic modeling. Let's examine the main features of these four groups.

1. Benefit-Cost Analysis

Benefit-cost analysis is recommended by the US Office of Management and Budget (OMB) as the technique to use in a formal economic analysis of Government programs or projects. According to the OMB Circular A-94 "Guidelines and Discount rates for Benefit-Cost Analysis of Federal Programs," benefit-cost analysis (BCA) is used "to support governmental decision to initiate, renew, or expand programs or projects which would result in a series of measurable benefits or cost extending for three or more years into the future."

The standard criterion used in BCA is the net present value (NPV) the discounted monetized value of expected net benefit. The NPV is computed by assigning monetary values to benefits and costs, discounting future benefits and costs using an appropriate discount rate, and subtracting the sum total of discounted cost from the sum total of the discounted benefit. Discounting benefits and costs transforms gains and loses occurring at different times to a common unit of measurement. Circular A-94 states that programs with a positive NPV increase social resources and are generally preferred. Programs with a negative NPV should generally be avoided.

The main problem of this method is that the NPV is not always computable because monetary values of some benefits and costs cannot be determined. To overcome

uncertainties in the BCA Circular 94A proposes to use comprehensive enumeration and quantifying of benefits and costs.

The main elements of the BCA are:

- Policy rationale. A rationale should be clearly stated in the analysis;
- Explicit assumptions. The analysis should include a statement of the assumptions, the rationale behind them, and the review of their strengths and weaknesses;
- Evaluation of alternatives by means, by different program scales, by methods of provision and by different degrees of government involvement;
- Verification of determination whether all anticipated benefits and costs have been realized.

Those working with the BCA should consider such variables as incremental benefits and costs, interactive and international effects, inframarginal and indirect benefits and costs. After that, analysts should include calculations for inflation and risks.

The results from the BCA are explicit and obvious. However, difficulties with the definition of benefits and costs of military indexes relevant to combat effectiveness make the BCA rarely used in military planning. Even though the BCA has special tools to deal with uncertainties, the huge number of those uncertainties makes it extremely difficult to use in real tasks.

Three limitations of the BCA are common. First, analysts may be unwilling or unable to monetize the most important policy impacts. Second is that any particular effectiveness measure does not capture all of the social benefits of each alternative. Finally, analysts frequently deal with intermediate goods which linkage to preferences is not clear.

In such cases, commonly-used alternatives to the BCA are cost effectiveness and cost-utility analysis.

2. Cost-Effectiveness Analysis

If all alternatives are mutually exclusive, and the status quo is among the alternatives, sharing similar scales and patterns of cost and benefit, then cost effectiveness analysis does select the most effective policy.
(Boardman, p. 396)

OMB opinion holds that cost-effectiveness analysis (CEA) is less than a "comprehensive technique, but it can be appropriate when the benefits from competing alternatives are the same or where a policy decision has been made that the benefits must be provided."

According to the OMB Circular NO A-94 a program is cost effective, if on the basis of life cycle cost analysis of competing alternatives, the program is determined to have the lowest cost expressed in present value terms for a given amount of benefits. Cost effectiveness analysis is appropriate whenever it is unnecessary or impractical to consider the dollar value of the benefits provided by the alternatives under consideration. This is the case whenever (1) each alternative has the same annual benefits expressed in monetary terms; or (2) each alternative has the same annual effects, but a dollar value cannot be assigned to their benefits. An analysis of alternative defense systems often falls in this category.

In comparison with the BCA, cost-effectiveness analysis produces a ranking but does not provide explicit information about whether there would be positive net social

benefits associated with any of the alternatives being considered. Since CEA does not monetize benefits, it inevitably involves two different metrics: monetary cost and an effectiveness measure. Because of the nature of these metrics and scale differences one cannot add or subtract one from another. Thus it is a measure of economic efficiency.

In practice, CEA almost inevitably reduces negative impacts that would be included in BCA. Indeed, CEA typically considers only the measures of effectiveness. Military projects usually have multiple objectives and benefits. Moreover, the necessity of obtaining an arbitrary ranking increases, as alternatives become less similar in terms of the inputs and outputs. From this point we enter the area where cost-utility and multi-attribute utility analysis give the best result.

3. Cost-Utility Analysis

Cost-utility analysis (CUA) relates budgetary cost to a single benefit measure, but its benefit measure is a construct composed of several benefit categories. Boardman believes that "CUA can be thought of as a form of CEA employing a more complex effectiveness measure." (p. 403) As CUA involves two or more distinct variables the analyst must designate how these variables are to be defined and combined. This is a problem in multi-attribute decision making.

Utility analyses are useful in two important areas: (1) to quantify attributes that don't have an obvious unit of measurement, and (2) to quantify and model a decision-maker's propensity to accept or to avoid risk. (Marshal, p. 249) The most difficult part of such an analysis is to obtain a utility function. Sometimes it is unrealistic, unclear or

too risky. But this does not negate the usefulness of this procedure in decision modeling. Indeed, the process of utility function construction often gives insight and clarity to the problem.

There are two ways to determine a utility function when decisions are made under conditions of uncertainty. One is when an indifference probability is found for a fixed risky venture. Another way to determine a utility function is when a riskless alternative payoff is found that is equivalent to the expected payoff of a given risky venture with even odds of success.

At a strategic level of military planning, the effectiveness measure for a decision problem may be captured by criteria such as readiness, sustainability or force projection. Some attempts to model these problems have an inherent but usually unstated, assumption that because no measurement units exist, the attributes can be represented by dimensionless quantities. To prevent inconsistencies in model output, Kneale Marshal states and uses the following principle as a fundamental guide in model building:

> *For a multi-attribute decision model to be consistent it should apply the same rules for combining attributes that cannot be measured directly as it does for those that can. If the problem under consideration has performance attributes for which there are no obvious measurement units, one should not assume that the weights assigned to these attributes are dimensionless and hence can be normalized in an arbitrary manner.*

4. Dynamic Modeling

Computers allow analyst to make huge calculations rapidly. Computers also allow them to use more and more complicated models in simulation of real processes. There are many different models for simulation of military actions and even regional wars.

Many military planners and scientists have found these models useful for resource allocation planning. Multi-level dynamic models can simulate reality, changing inputs in accordance with a given scenario and state of outputs. Modern models of global and local military conflicts are based on complicated probabilistic scenarios and complex mathematical theories. These models let researchers evaluate the influence of entire weapon systems, or just their parameters, on the result of simulated military operations. Clearly the quality of the results in dynamic modeling depends strongly on the details of the model, the quality of assumptions and simplification. The results received in different stages of simulation may then be used to construct specific cost-effectiveness or cost-utility indexes for decision making.

For example the DynaRank methodology (Hellestad, p. 7) can work with multiple objectives and rank policy options by cost-effectiveness. Each ranking is a judgement about the relative importance of higher level objectives and a variety of success criteria. It can also be used to integrate a detailed analysis with emphasis on components of defense strategy.

On the other hand, complicated models have to work with stochastic elements involved in the simulations. These means that every new run can give different results, and repeated simulation runs may result in different sets of summary performance measures.

B. ANALYSIS OF ALTERNATIVE MEASUREMENT SCALES

Decision-makers deal with four different levels of measurement: nominal, ordinal, interval and ratio. Money, often the main index in analysis, has ratio measurement. Analysts always try to work with compatible indexes when assessing different policy alternatives. In this case it would be easy to say that doubling commodities doubles money cost. Unfortunately, when we use effectiveness or utility as indexes in analysis, it is sometimes very difficult to make the right decision due to the scale differences.

In simple cases, when all of the policy alternatives have the same cost, scale differences do not cause a problem. If, in addition, the cost-effectiveness analysis is inclusive of all social costs and benefits, then CEA ranks alternatives in terms of allocative efficiency. Similarly, scale is not a problem if the level of effectiveness is constant across all alternatives. In case of fixed effectiveness, CEA corresponds to a simple cost minimization problem, while in the fixed budget case CEA corresponds to a simple effectiveness optimization problem.

In real problems we can find that large scale differences among alternatives can distort choice. For example, we have two exclusive alternatives. In the first case we can invest $10 million in flight safety and save ten lives a year. The second alternative will cost $200 million and would be able to prevent 100 military casualties in a conflict. Due to the simple cost effectiveness ratio, the first alternative is twice as effective as the second. But the second alternative can save ten times more lives in certain conditions.

A different problem arises if the decision-maker must select between indexes that are in different measurement scales. An example of such a problem is how to select

between the ordinal ranking of some radar qualities and the ratio measures of additional weight relevant to this change. Different methodologies propose different approaches to convert scale and measurement differences to compatible results.

The first method is normalization. TASCFORM methodology, for example, uses the F-4B as a basis for comparing different aircraft. Then it computes the ratios of all performances of evaluated aircraft to F-4B's performances. The methodology effectively constructs a ratio scale in terms of F-4B equivalents, but the constructing scoring system doesn't determine the utility of F-4B equivalents.

Utility theory proposes another way to solve a measurement problem. Single utility functions (SUF) let us transform differently measured attributes to a common unit called "utility." Actually SUFs play the role of normalization of different measures to common measures with interval values. Individual trade-off between attributes, in different methodologies that use utility theory, are usually based on personal judgement. In this case we receive an interval ranking of alternatives.

Probabilities and uncertainties when added to analysis may change scales of results. As a result, when the lottery option discussed above is used, one can obtain a scale that has interval properties in the sense that linear transformations of the utility function can be taken without changing the decision. However, one really obtains an ordinal scale for utility when the developed utility function is used to assess alternative combination of utility and some other variable, such as cost, is not included in the utility function.

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III. CASE. MIG-29 MODERNIZATION DECISION

The ultimate goal of military economics is to discover the truth about relations between military goals and the economy in the real world. There are many ways to seek the truth. Some scholars believe in empirical verification as evidence supported by theory; others assert that truth can be discovered only by logical deduction. The methods may vary, but the common element is the reliance on models. A situational model for methodology evaluation is an independent element of analysis. It can be used for all evaluated methodologies without sufficient changes. Moreover such a model should be "method neutral," so it shouldn't influence the final results by giving advantages to any methodology. The best index of effectiveness for a modernization decision is *Force Potential*. This means that a model should have *Force Potential* as an output.

A common organizational model that satisfies most present demands is the McCaskey model. (Figure 1). First, this model includes all the factors that can influence a modernization decision. Second, this model describes the interconnections of the elements. Finally, this model allows us to use integrated indexes such as *force potential* for analytical purposes. But, this model is too broad for numerical analysis. Practical models are usually derived from methodology and analysis demands. So, what are the main features of the Ukrainian Air Force that should be under considered for modernization modeling?

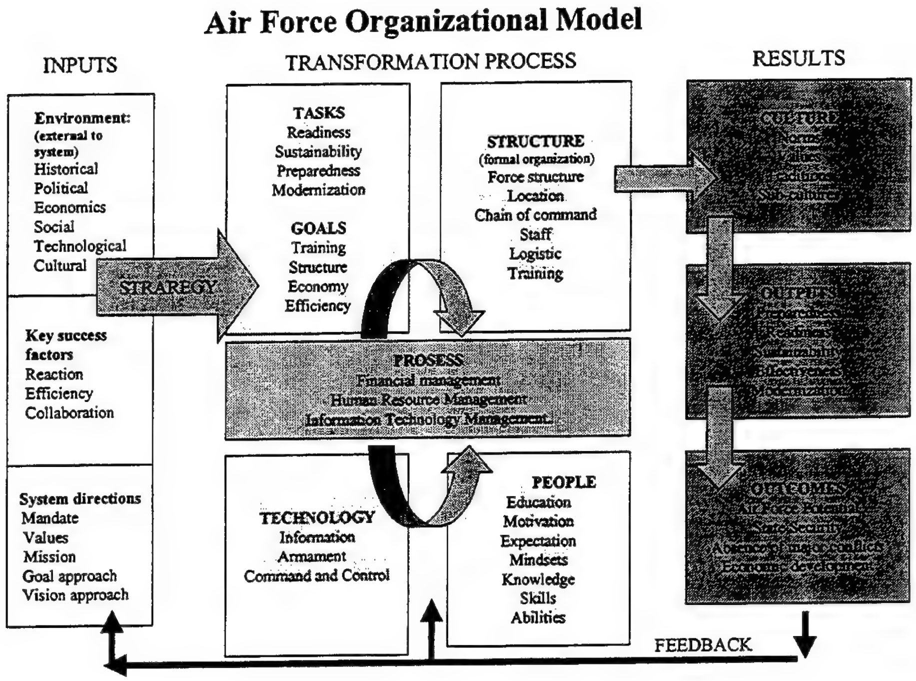


Figure 1. Air Force Organizational Model

A. ENVIRONMENT AND DIRECTIONS

The main elements of the external environment of the Ukrainian Air Force are the State, its security formations, politics and the economy. Strategy and doctrine set the main directions.

Ukraine is a non-nuclear state and is defensive in character. At a doctrinal level, the Ukraine does not recognize territorial claims upon itself or hold territorial claims on other states. The technical aspect of military doctrine emphasizes defense sufficiency.

Guided by the principles of non-participation in military blocs and alliances, which the country remains faithful to, the Ukrainian army is now prepared to fight only

on its own territory. This really means that the Ukraine, unlike many European NATO countries, cannot afford a small or a weak army.

The Ukrainian military for the last five years have implemented territorial principle of defense strategy and new military administrative organization. The next step of the military reform will be reorganizing divisional structure to a brigade-battalion system. The Air Force will shrink to 10-12 brigades. In addition 600 aircraft and 400 helicopters will be transferred from combat units to reserve or will be disassembled.

The state intends to support a technical level of modernization with thorough modernization of its existing weapons. The state weapon program announced that the lifetime of the main armament will be increased to 10-15 years. Also the procurement of new weapons will be minimized.

Financial support of the army is insufficient. Ukraine's military budget for the year of 2000 is Hr2.4 billion ($480 mil. One dollar approximately equals five hrivnas.) Objective data shows that for the last several years the army has been underfinanced. Hr 2.4 billion military budget in existing conditions permits weapon R&D plus procurement in the level of approximately Hr300 millions. ($60 mln.) So, one can say that the Ukrainian military has already lost one important campaign – the budget war. For the year 2000, they received less than half of what MOD analysts have estimated to be their minimum needs.

The present external environment for Ukraine can be characterized as friendly or neutral. On the other hand, all the main neighboring countries have different historical claims for different parts of Ukrainian territory. The Ukraine has cultivated a good

relationship with NATO. It was the first CIS State to join the Partnership for Peace (PfP). There are a number of special agreements between Ukraine, the United States, Russia and NATO. These agreements were created to increase state security after Ukraine's nuclear disarmament.

Ukraine's economic potential is considerable; it has strong agricultural traditions, a large domestic market and trained labor, a diverse industrial base and substantial natural resources. However, the economic development has been slow and reforms inconsistently applied and frequently subject to bureaucratic interference at both national and local levels. The Ukraine depends on imported energy from Russia and Turkmenistan. The foreign debt equals $13.5 billion.

Owing to a new state program, by December 31, 1999, the Ukrainian army will have 310,000 serviceman and 90,000 civilian employees. The state armament program will include R&D in the areas of a new missile complex for ground forces, a new anti-aircraft complex for the air defense and an aircraft modernization program. The division of personnel and the composition of Ukrainian armament are given in Figures (2) and (3). The Air Force structure is presented in Figure (4).

Armed Forces (1999)	**Strength**
Total Armed Forces	326, 000
Army	171, 300
Air Force	124, 400
Navy	12, 500

Figure 2. Division of Personnel in Ukrainian Armed Forces

Type	Armored Vehicles	Combat Aircraft	Major Combat Vessels
Number	12, 670	948	27

Figure 3. Armament of Ukrainian Armed Forces

##	TYPE	ROLE	QUANTITY	IN SERVICE
1	MiG-23 ML,MLD/UB	Interceptor/Trainer	100/27	100/27
2	MiG-29-16	Interceptor	161	161
3	SU-17	Ground Attack	39	39
4	SU-24MP/MR/U	Bomber	160/43/48	160/43/48
5	SU-25	Close Air Support	34	34
6	SU-27	Interceptor	70	70
7	TU-22/m3	Bomber	33/29	33/29
8	An-12/24/26/ IL-76	Transport	40/30/30/188	40/30/30/188

Figure 4. Main Inventory of Ukrainian Air Force

B. STRUCTURE AND TECHNOLOGY

Ukraine's current adherence to the CFE treaty limits it to 1,090 combat aircraft, 330 armed helicopters and 100 naval aircraft. Aircraft assets is divided 75:25 between the Air Force and the Air Defense.

According to the new concept, the basic structure of the Air Force will be a brigade consisting of 4 to 5 squadrons, and 12 to 14 aircraft each. The brigade will have

one basic airfield where all structures are based during peacetime and may have up to four reserve airfields for maneuvers. The brigade might have one or two types (modifications) of the aircraft of the same class. The normative ratio of pilots to aircraft is 1.5:1. Air Force norms say that fighter pilots must have 90 to110 flight hours a year to maintain or increase their proficiency. Presently the real flight rate of Ukrainian pilots is about 40-50 hours a year. This is really a small number in comparison with NATO's standard of 150 to 220 flight hours.

Each air squadron has its own maintenance command, which is able to work autonomously from the base. Squadron engineers and mechanics are able to localize any defect and to perform simple repairs and regulation tasks. The brigade technical unit provides periodical maintenance (each 100, 200 or 500 of flight hours). The brigade is also the main unit for combat-damage repair. Periodical repair (1500 to 3000 flight hours), upgrade and modernization are usually handled by air depots - separate military units connected to center or territorial command. Every depot has a narrow specialization according to the types or models of aircraft. The air industry of Ukraine is able to design and produce modern transport and civilian aircraft. There are two major air assembly plants, one engine plant and several aggregate, avionics and radio equipment plants in the industry.

C. ALTERNATIVES

The Ukraine Air Force has 161 MiG-29 fighters. 90 of them (two brigades) are aircraft model MiG-29S (design bureau index 9-13) which fit the MiG-29SMT

modernization program. All of them have sufficient lifetime and technical conditions to be modernized.

Let us assume that the Ukrainian MOD is in the process of the MiG-29 modernization program selection. The money available for this program for five years is \$100 millions. Forty million is earmarked for the first year and \$30 million is appropriated for the second and third years respectively.

The Air Force command (1), The Air Force University (2) and the General Staff Aviation Planning Group (3) have presented three different alternatives:

- MIG MAPO MiG-29SMT program (Air Force command). (MAPO is Russian abbreviation for Moscowskoe Aviacionnoe Proizvodstvennoe Ob'edinenie);
- MAPO-DASSO program (Air Force University);
- Intensifying training program without major modernization (General Staff).

After the initial discussions are completed, the MOD military board ordered the Armament Department to conduct a military-economic analysis of the alternatives. As the index of effectiveness, the experts needed to use the integrated combat potential of the Air Force brigade for five years. Analysis experts agreed to use two different tools: (1) TASCFORM methodology (Timperlake, 1-2) and, (2) Logical Decision for Windows (LDW). The Data available for alternative's assessment are shown in Figure (5). The qualitative description of proposed alternatives is given below.

N	PARAMETER		PHYS. DISC	ALTERNATIVES		
				MIG-29s	Mapo Dasso	Mapo SMT
	Service life		Hours	4000	5000	6000
	Max weapon load		kg	4000	4000	4500
	Operating weight (empty)		kg	10900	11000	12500
	Max fuel load		kg	4640	4640	5600
	Normal T-O weight		kg	15300	15400	16000
	Range		km	1565	1565	2100
	Missile range		Km.	50	50	110
	Useful air speed		km/h	2440	2440	2440
	Trust		kn.	16600	16600	21000
	Maximum take off weight		kg	18500	19700	21300
	Speed	Max	km/h	2445	2445	2445
		S/L		1500	1500	1600
		T/O		260	260	260
	Max rate of climb at S/L		m/min	19800	19800	21000
	Service ceiling		m	18000	18000	18500
	Radius of Turn (3.8g)	800 km/h	m	350	350	350
		408km/h		225	225	225
	Range	With max internal fuel	km	1430	1430	2100
		With underbelly tank		2100	2100	2800
		With three fuel tanks		2900	2900	3500
	G limits	Above M0.85		7.5	7.5	7.5
		Bellow M0.85		9	9	9
	Radar	Detection range (fighter)	km	100	100	130
		Tracked targets		10	10	10
		Engage		2	2	4
	Air-to-air	Long range				(2)
		Mid range		2	2	4
		Short range		4	4	4
	Air-to-ground	Unguided bombs		+	+	+
		Guided bombs				+
		Missiles				+
	Power plant	Type and number		2 x RD33	2 x RD33	2 x RD43
		Thrust	KN	49.4	49.4	
		Thrust +Afterburn.	KN	54.9	54.9	98.1
		Lifetime	Hours	900	900	1500
	Base of avionics			Specialized computer	MIL-STD-1553B	MIL-STD-1553B
	Navigation System			RSBN RSDN	GPS Glonass RSBN	GPS Glonass RSBN

Figure 5. Initial Data for Modernization Decision

1. The MiG-29SMT Program

I assume that the fixed cost for both the SMT and the MAPO-DASSO program is $10 million. This includes the cost of the technological documentation, any additional equipment and personnel training. The variable cost of SMT program is $3 million for each aircraft, including the cost of new aircraft equipment, labor and overhead. Lviv's air depot estimates that it would be able to modernize 10 aircraft a year to the SMT level after a six-month preparation period.

The main features of the program are:

- lifetime prolongation complex;
- increasing fuel capacity;
- upgraded radar;
- a new air-to-air and air-to-ground weapon;
- new countermeasure equipment;
- upgraded avionics and cockpit;
- radar dissipating coating. (Polushkin, p. 6)

2. The MiG-29 MAPO-DASSO Program

The variable cost for the MAPO-DASSO modernization is $ 1 million for each aircraft. One air depot after a three-month preparation period can provide modernization of 30 aircraft a year. The main features of this program are:

- IFF transponder with all current modes;

- A free selectable VHF/UHF communication set, emergency communication and collision warning lights;

- Lifetime enlargement program (1, 100 flight hours);

- GPS system with a 1553B databus link to an aircraft navigation system, plus an enhanced 1553B databus compatible system with an integrated laser-internal navigation system. (Mader, p. 3)

3. Training Program

Contrary to groups presenting particular modernization programs, the operational planners propose to spend any available money to intensify the Air Force training program. Their argument is based on the fact that pilots don't receive sufficient training and any investment in aircraft will produce minimum benefits. Combat effectiveness depends on both aircraft performance and crew proficiency, so modernization is cost effective only with a certain level of pilots training. Presently the average flight time for pilot is 40 to 50 hours a year. The data and calculations presented by the General Staff group show that the best results can be reached by spending the available money in the following ways:

- aircraft's lifetime prolongation program for five years - \$20 million;
- spare parts - \$15 million;
- modern training equipment and simulators - \$15 million;
- fuel and materials (\$10 mln./year) x (5 years) = \$50 million.

The cost of fuel appears to be the only variable cost for the flight-intensifying program. The Air Force should at any rate spend money for personnel and base

maintenance with or without flights. Costs of aircraft and equipment are sunk in this case and costs of other materials are significantly smaller than the cost of fuel.

Aircraft fuel in the Ukraine is about $400 1, 000 kilogram. An additional $10 million a year remains to buy 2 5, 000 tons of fuel. MiG-29 consumes approximately 3 tons of fuel in a one-hour flight. This gives the Air Force an additional 8,300 flight hours. For each of 130 pilots of two MiG-29 brigades this cost roughly provides 65 additional flight hours per year for five years. Together with the available flight time this number will reach about 100 hours a year per pilot.

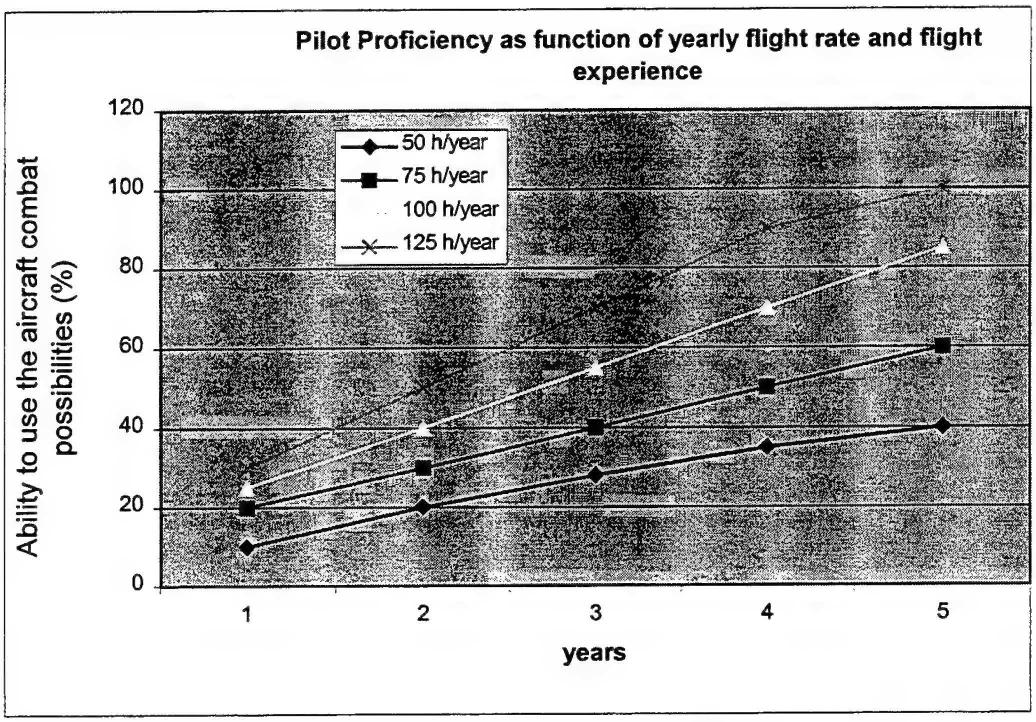


Figure 6. A Pilot's Proficiency as a Function of Training

For analytical purposes General Staff analytical group assumes that the proficiency of pilots depends on experience and annual training activity. Proficiency here

is the percentage of usage the aircraft combat capabilities. Figure (6) shows proficiency as functions of flight experience and the yearly flight year rate.

D. TASCFORM-AIR MODEL

The Analytic Scientific Corporation (TASC) has developed a method to quantify military force modernization based on the measured performance characteristics of a specific military system. TASCFORM provides statistic indicators of military force potential called measures of effectiveness (MOE's). The measurements of force effectiveness also include quantities of individual weapon systems and are expressed as numerical scores. Figure (7) shows the structure of the TASCFORM AIR model results.

Individual system measures of effectiveness for aircraft are determined by comparing performance characteristics such as payload, range, speed, maneuverability and targeting to those same characteristics of a specified baseline aircraft. The relative importance of these characteristics for each mission is accounted for through by weighting factors developed by the panel of experts using Delphi-like techniques.

Calculated individual weapon systems values can be used alone or they can be combined with inventory level and crew proficiency to produce an aggregate theoretical force potential. (Regan, p. 1-1)

Finally it should be noted here that the TASCFORM-AIR methodology does not, in its present form, consider cost as input. The model attempts only to measure capabilities as an output. Consequently, the measures of effectiveness are not

synonymous with cost effectiveness, and care must be taken to avoid reaching conclusions relative to cost effectiveness when comparing one system's measures of

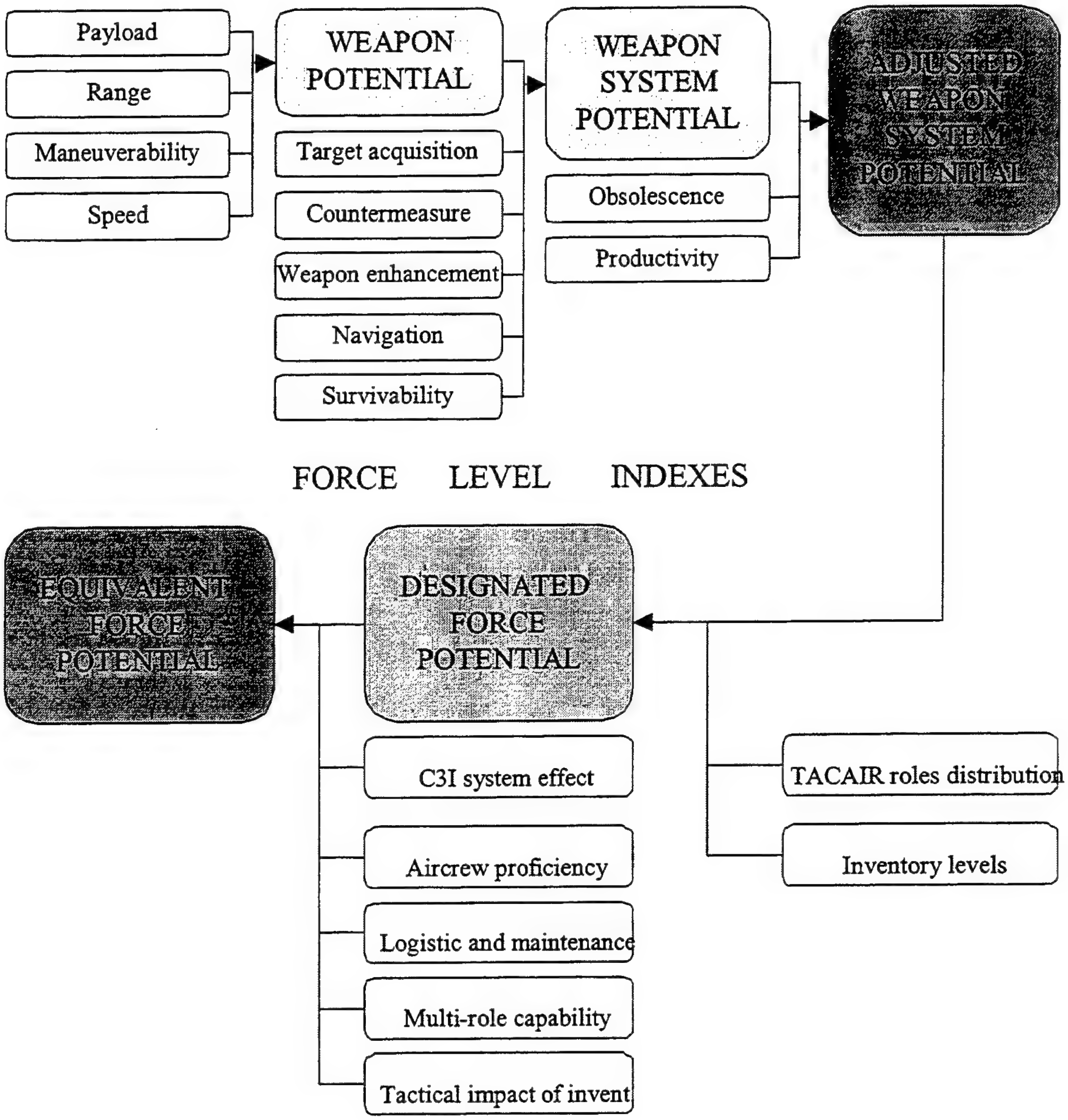


Figure 7. TASCFORM Indexes

effectiveness with that of another. On the other hand, in our problem, an available budget is constant for all alternatives. This budget defines a number of aircraft to be modernized (MIG-29 MD, SMT), or increased the level of aircrew and groundcrew proficiency due to better financing. All these parameters are included in force potential level measures of effectiveness. Therefore, in force level we can consider measures of effectiveness as a cost effectiveness index.

A detailed description of the methodology is given in Appendix (A). Excel-based calculations of alternatives are given in Appendix (B).

E. LOGICAL DECISION FOR WINDOWS SOFTWARE

Logical Decisions for Windows (LDW) software and methodology is based on Multiattribute Utility Theory (Appendix C). It helps to evaluate decisions quantitatively. Analysts have to define alternatives and their variables. LDW methodology describes alternatives by measures, which are numerical or descriptive variables that capture some quality of alternatives.

The measures in LDW are organized under goals; concerns that may affect choice. The software helps to organize goals and measures into a hierarchy. LDW uses an overall score, called utility, to rank the alternatives. The program computes an alternative's utility by combining its measure levels based on the analyst's preferences. Hierarchy of goals for aircraft modernization is shown in Figure (8).

The LDW provides considerable flexibility in alternative evaluation; therefore, several basic steps are common. First, the analyst must structure the problem as a

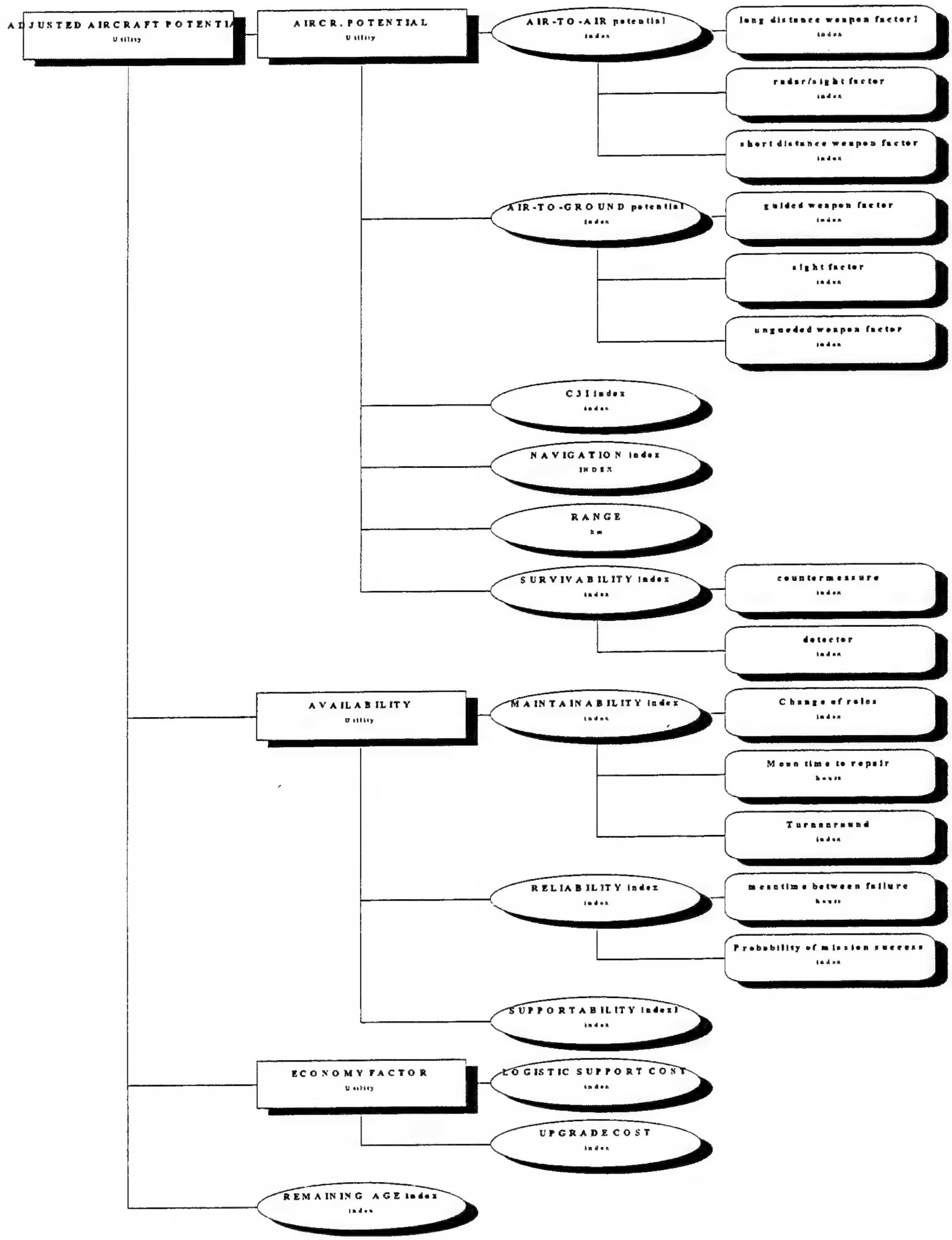


Figure 8. LDW Modernization Model's Hierarchy of Goals

hierarchy of goals, measures and measure categories. After that the analyst has to describe the alternatives. The ability of LDW to transform the data to utilities allows one to use a wide scope of physical, financial data and even social values to describe competing alternatives.

The next step is the assessment of preferences. LDW provides a large variety of analytical methods to state relations between independent and dependent variables.

Finally, the program ranks the alternatives and provides the results in a number of ways; numerical, graphical and probabilistic.

The force level utilities in our model are based on multiplicative approach similar to TASCFORM methodology and PEREGRINE model (Appendix D).

Appendix (F) presents short description of different decision support and accounting software available for decision-makers.

IV. ASSESSMENT OF METHODOLOGIES

As with any complex subject, the methodology for a modernization decision cannot be assessed using only one or two parameters. Three main parts of methodology are important for decision-makers. The first part is the initial data required for analysis, including constants and variables (input). The second part includes algorithm, assumptions and axioms (model). The third part of the analysis is the results developed by the methodology to make or support decisions (outcomes).

In addition to comparing these elements, I will try to analyze the application of methodologies to a given problem, the inherent subjective factors of both methods and the influence of these factors on the model and on the results.

A. INITIAL DATA

The initial data for modernization decision are numerous aircraft characteristics, such as performance and mass-geometric data, indexes of effectiveness, economy and reliability factors, lifetime resources, etc.

One can distinguish two situations with aircraft modernization decision-making relevant to initial data. The first is when a modernization decision is based on data of existing prototype, and second – when the decision is based on the estimated data of the modernization program. In the first case the decision-maker has more or less reliable statistical data of the aircraft's physical performance. In the second case, an analyst should deal with estimates of data and performance that are usually described with

certain probabilities. Since the main task of this thesis is methodology assessment and comparison, I will assume that the availability and the accuracy of the data used in the thesis computations are equal to the data available for MOD level of analysis. Available numerical data are sufficient for both TASCFORM and LDW methodologies.

There are several sources of data used by MOD analysts for aircraft modernization decision. The first source is the design bureau manuals and technical reports. Most countries that produce aircraft have state flight-test centers. Their test reports usually have priority above all other sources. For modernization program selection purposes, in the case a prototype doesn't exist, analysts can use additional independent sources such as scientific research and publications, specialized journals and the estimations of experts. Common data describing modernization programs and status quo are given in Figure (5).

B. ADITIONAL DATA REQUIRED BY METHODOLOGIES

Scope of the data actually used by analysts is much wider than data given in the table. For example, to estimate the performance of an aircraft's radar one should consider several dozens of parameters: signal power, sensitivity, weight, accuracy, reliability, countermeasure sustainability, weight, cost, maintainability etc. With more details, one can assess numerous characteristics for each element. For instance detection range of the radar can be described for high, middle and low altitudes, for different weather conditions and for various landscapes under the aircraft. In addition, target speed

and relative target position can influence detection range. This shows that detailing of the model may significantly complicate any problem.

Therefore one of the most important problems for decision-makers is to agree on is "How much initial data is enough?" To make such a decision the analyst has to make several assumptions and approximations, which help to simplify the problem. So, what are the main assumptions and additional data required by the TASC and LDW models?

1. TASCFORM Air Model

The TASCFORM Air Model generates measures of effectiveness for individual aircraft and for tactical Air Forces. Appendix (A).

There are four types of data required by this model:

- Performance numerical data;
- Expert's weighting factors;
- Model constants;
- Data of the aircraft that is used for normalization.

Performance in this model is actually the median of various data received and estimated by design bureaus and by the testing centers. All this data can be described by the distribution functions.

A weapon potential score is computed by scoring the airframe, power plant and payload characteristics and normalizing that score against a baseline aircraft, the U.S. F-4B. Subjective weighting factors (Figure 9) assign relative importance to the characteristics depending on how they contribute to the air combat or surface attack role.

In cases where a new model of an existing aircraft possesses a significant change in capability (MiG-29md/smt), that model is treated as a separate aircraft.

N	Characteristics			Index.	Weighting Factor	
					Fighter	Interceptor
1	Payload			Fpl	3	4
2	Range			Fr	2	3
3	Maneuverability			Fm	3	1
4	Useful Air Speed			Fv	2	2
5	Target Fraction	Guided Weapon Non-guided Weapon		TFgmr TFngmr	0.8 0.2	0.9 0.1
6	Target Acquisition Capability	Clear Day Clear Night Limited All Weather Good All Weather		TAxxxrt	1.0 1.0 1.2 2.0	1.0 1.2 1.6 2.0
7	Guided Munition Engagement Factor	Within Visual Range	Semi-active Active homing Multi-target Off-bore Site	GMErt	0.8 1.0 1.2 1.4	0.8 1.0 1.2 1.8
		Beyond Visual Range	Semi-active Active homing Multi-target Long-rangeMT		0.8 1.2 1.6 ---	1.0 1.6 2.0 3.0
8	Countermeasure Susceptibility Factor		Very high High Average Low Very low	CMrt	0.7 0.8 0.9 1.0 1.1	0.7 0.8 0.9 1.0 1.1
9	Guided Weapon Enhancement Factor		US NATO/WP	WEtgm	1.2 1.2	1.2 1.2
10	Navigation Capability		Poor Fair Good	NAVr	0.8 1.0 1.0	0.8 1.0 1.0
11	Useful Lifetime			ULr	15	25
12	Basing Factor		V/STOL STOL CTOL	BF	200 450 750	

Figure 9. TASCFORM AIR Model Weighting Factors and Constants

presents all the data used and the results of the TASCFORM-AIR model for MiG-29 modernization decision.

2. LDW Aircraft Modernization Model

In contrast to the TASCFORM AIR Model, the LDW method doesn't propose specialized algorithm for any specific problem. It proposes a method and universal software for most decision-making problems. A detailed description of the LDW isn't the subject of this thesis, so I'll emphasize only the main points of the solution and qualities of the methodology relevant to my comparison with the TASCFORM AIR Model.

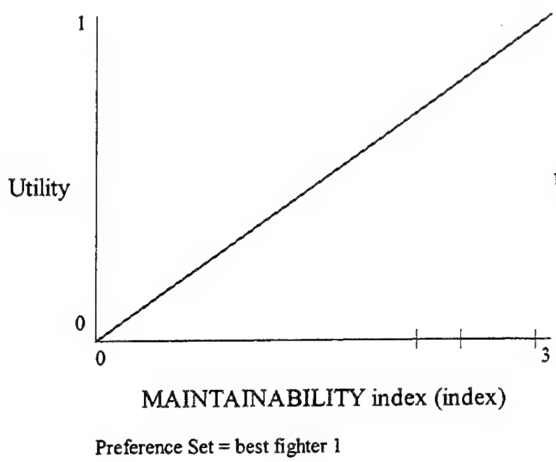
Actually LDW allows one to replicate the TASCFORM approach and to obtain the same results. It can use all the formulas of the TASCFORM AIR Model and its weighting factors. But it is not the most convenient way to use LDW.

In the modeling modernization decisions one can conclude that there are only certain specific factors, which are really influenced by modernization. So, an effective solution may not include all the factors and characteristics of the aircraft but rather, just the ones that actually change. For comparison purposes, Adjusted Aircraft Potential (AAP) is herein selected as the main goal for LDW modernization model. (Figure 8) Similar to the TASCFORM Adjusted Weapon System Potential (AWSP), AAP includes several lower level goals such as aircraft potential and availability. In contrast to TASCFORM, AAP also includes economy factors and remaining age index.

LDW converts the alternative's measure levels into common units – utility. The highest utility is equal to one, the lowest is equal to zero. Intermediate levels are assigned with what is called a Utility Function, or more specifically a Single Utility Function (SUF). The easiest representation of SUF is a straight line. This is the most common case, and the default. If straight lines SUFs aren't appropriate, any kind of

N	Measures/ Overall Weights	Measure Categories	Category Multipliers	Alternatives		
				MiG-29MD	MiG-29S	MiG-29SMT
1	Air-to-air potential 0.105	Long distance weapon factor	1.0	0.6	0.6	1.0
		Short distance weapon factor	0.8	0.5	0.4	0.6
		Radar/Sight factor	1.0	0.5	0.4	0.8
2	Air-to-ground Potential 0.070	Guided weapon factor	1.0	0.0	0.0	1.0
		Unguided weapon factor	0.5	0.5	0.5	0.6
		Sight factor	0.5	0.5	0.4	0.7
3	C3I Index 0.053			1.0	0.6	0.8
4	Navigation Index 0.053			1.0	0.7	0.85
5	Range 0.035			1500	1500	2100
6	Survivability Index 0.035	Countermeasure	1.0	0.6	0.5	0.7
		Detector	1.0	0.5	0.35	0.7
7	Maintainability Index 0.075	Change of roles	1.0	0.6	0.6	1.0
		Mean time to repair	1.0	1.0	0.8	1.0
		Turnaround	1.0	0.8	0.7	0.9
8	Supportability Index 0.035			0.8	0.6	0.9
9	Logistic Support Cost 0.070			0.8	0.7	1.0
10	Upgrade Cost 0,.130			0.8	0.75	1.0
10	Remaining Age Index 0.200			12	8	5

Figure 10. Data Assigned for LDW Aircraft Modernization Model



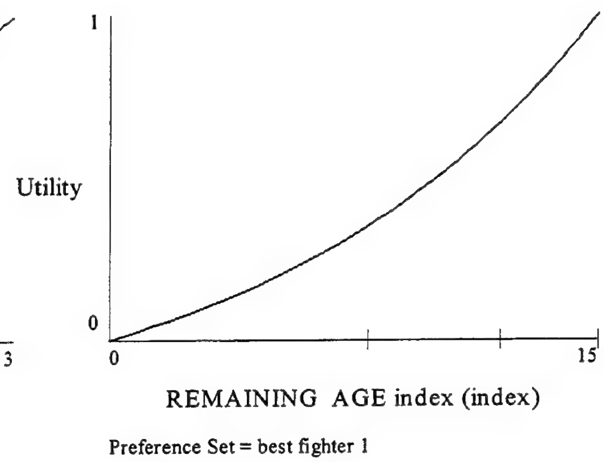


Figure 11. Forms of Single Utility Functions Used in LDW Modernization Model

monotone non-linear function can be applied. Figure (11).

On the next step LDW computes a goal utility by combining the utilities for each of its member in a weight average. Similar to the TASC weighting factors the LDW model member's weight determines how much it will influence an alternative's utility for the goal. LDW provides several methods for assessing weights. The simplest method uses a simple ordering of the measures' relative importance. Other methods, such as "smart" and "analytical hierarchy process" have analysts enter the ratios of the measure's relative weights. Another method called "tradeoff" is based on the idea that equally preferred alternatives should have equal overall utilities.

Finally LDW provides many ways to review results. It can rank the alternatives overall goal or a measure. LDW sorts alternatives by utilities and displays them along with a bar representing a relative score.

C. APPLICATION OF METHODOLOGIES

The pursuit of efficiency in the military requires a priority to be given to those programs, that provide the greatest benefit per unit of cost. Alternative actions often have to be compared to determine whether a change in the mix of actions would increase efficiency. Also the economic evaluation approaches the cost in a common format, yet they differ in the ways they approach benefits. These differences play a critical role in developing criteria for efficiency.

So, what aspects of the models do influence the methodology selection, and what aspects of the methodologies influence the selection of criteria?

1. Hypothesis

Two main hypotheses have influenced the selection of methodologies and criteria for a modernization decision. The first is that effectiveness of the aircraft is primarily a function of the aircraft potential and the pilot proficiency. Therefore, investing in the aircraft's modernization is cost-effective only from a certain point of crew proficiency. The second hypothesis is that the varying money available for modernization may change the nature of the best solution. In this case it depends on the difference between marginal benefits of modernization and training.

These hypotheses firstly led to including the status quo plus training alternative for consideration. Secondly, the assumed hypothesis predetermined the choice of the force level indexes of effectiveness as criteria. Finally, both hypotheses provide a better understanding of the real goals of economic analysis in the military.

2. Criteria of Efficiency

Efficiency in military resource allocation matters whether these resources are being used to get the best value for money or not. Efficiency is concerned with the relation between resource inputs and either intermediate outputs (in our case aircraft potential) or final military outcomes (force potential, readiness, etc.). Also many evaluations use intermediate outputs as a measure of effectiveness, this leads to possibly suboptimal recommendations. Ideally, economic evaluation should focus on final military outcomes.

There are three main concepts of efficiency in the theory: technical, productive and allocative. Technical efficiency addresses the issue of using given resources to the maximum advantage; productive efficiency of choosing different combination of resources to achieve the maximum benefits for a given cost; and allocative efficiency of achieving the right mixture of military programs to maximize force potential. Although productive efficiency implies technical efficiency and allocative efficiency implies productive efficiency, none of the converse implications necessarily hold. Faced with limited resources, the concept of productive efficiency will eliminate as "inefficient" some technically efficient resource input combinations, and the concept of allocative efficiency will eliminate some productively efficient resource allocations. (Palmer, p. 2)

TASCFORM-AIR Model generates measures of effectiveness for the individual aircraft and based on it – for the tactical air forces. As far as these indexes are ratio comparison of evaluated and basic aircraft, we can believe the results of TASCFORM evaluation is appropriate for cost effectiveness analysis. This cost effectiveness analysis

type of analysis measures military benefits in constructed indexes (weapon potential, force potential). Since costs and benefits are measured in non-comparable units, their ratios provide a yardstick with which to assess relative (productive) efficiency. This decision rule does not, however, enable us to evaluate the relative efficiency of actions, which provide more benefits at a greater cost or less benefits at a lower cost. A major limitation of cost-effectiveness analysis is its inability to compare alternatives with different natural effects. For example investments in air defense cannot be directly compared with those that improve air forces. Cost-effectiveness analysis therefore cannot directly address allocative efficiency.

Logical Decisions for Windows provides us with utilities for individual aircraft. In the case of linear approximations for single-utility functions and with the absence of probabilities in the model the result has an interval scale meaning. Force level measures of effectiveness are the results of the multiplication of an aircraft potential by the pilot's proficiency and inventory level. It lets us consider the aircraft potential and force potential based on LDW calculations as an index for cost-utility analysis. Generally cost-utility analysis is an adaptation of cost effectiveness analysis which measures the alternatives effect on both the quantitative and qualitative aspects of military indexes using a utility based measure. Like cost effectiveness analysis, relative efficiency is assessed using an incremental ratio, here a cost-utility ratio. An alternative is deemed productively efficient, relative to another one, if it results in higher (or equal) benefits at a lower cost. The use of a single measure of military benefit enables diverse alternatives to

be compared so cost utility analysis can address both productive efficiency and allocative efficiency.

In cost-utility analysis the optimal decision rule involves ranking the incremental cost-utility ratios of different alternatives and selecting those with the lowest ratios (best value) until the budget is depleted. The lower the incremental ratio, the higher the priority in terms of maximizing military benefits derived from a given level of expenditure. The point at which resources are exhausted defines a maximum price for a unit of effectiveness. Eliminating interventions with an incremental cost above this price in favor of those with lower incremental costs would be considered an improvement in allocative efficiency. (Palmer, p. 3)

3. Adjusting the Methodologies to the Model

Our situational model can be described as a model of the Air Force unit which consists of two brigades armed with MiG-29 (90 aircraft). Environment, directions, constraints and culture are common for all alternatives. The difference is in the "process" and "structure." Brigades may increase their combat potential by modernizing aircraft or by intensifying training.

The TASCFORM-AIR model doesn't demand any structural changes or adjustments to presented model. To construct the Equivalent Force Potential (EFP) measure of effectiveness, the following assumptions should be made:

- Structure of Brigade for each year shall be calculated in accordance with the scenario. For example, for the status quo alternative the number of the aircraft constantly equals 90 MiG-29S. For SMT and MD alternatives it is

a mix of the modernized and basic aircraft, which depends on the air depot productivity.

- Concept of pilot's proficiency in the model is based on assumption that a fully-trained pilot can use 100% of the aircraft potential. To achieve this result a pilot needs five years of intensive training (120-130 flight hours a year). A yearly flight rate of 50 hours let pilots keep theirs proficiency on the 50% level. For the five-year period, I assumed the linear approximation of proficiency function.

  $P1(t) = 0.5$ Flight rate 50 hours/year;

  $P2(t) = 0.09*Y + 0.5$ Flight rate 120 hours/year.

  $Y = \{1, 2, 3, 4, 5\}$, year of program.

Use of more complicated proficiency functions shouldn't create significant difficulties.

As mentioned earlier, the LDW is a methodological framework for decision support. Using LDW, the analysts create their own structure and logic for the problem based on their model and intentions. The basic structure of goal hierarchy for a modernization decision is based on the Grippen concept of aircraft effectiveness (Appendix F), adjusted TASCFORM weighting factors and PEREGRINE multiplicative approach for the force potential level of effectiveness. (Appendix D)

In our case, modernization influences a comparatively small number of aircraft performance measures. It helped to create a hierarchy with a relatively small number of measures and measure categories. (Figure 12). As far as the main purpose of this thesis is the evaluation of methodologies, not the evaluation of modernization alternatives, I assigned reasonable utilities and measures in the model where it was not available from

the references. The concept of force structure and pilot's proficiency remains the same as in the TASCFORM-Air model.

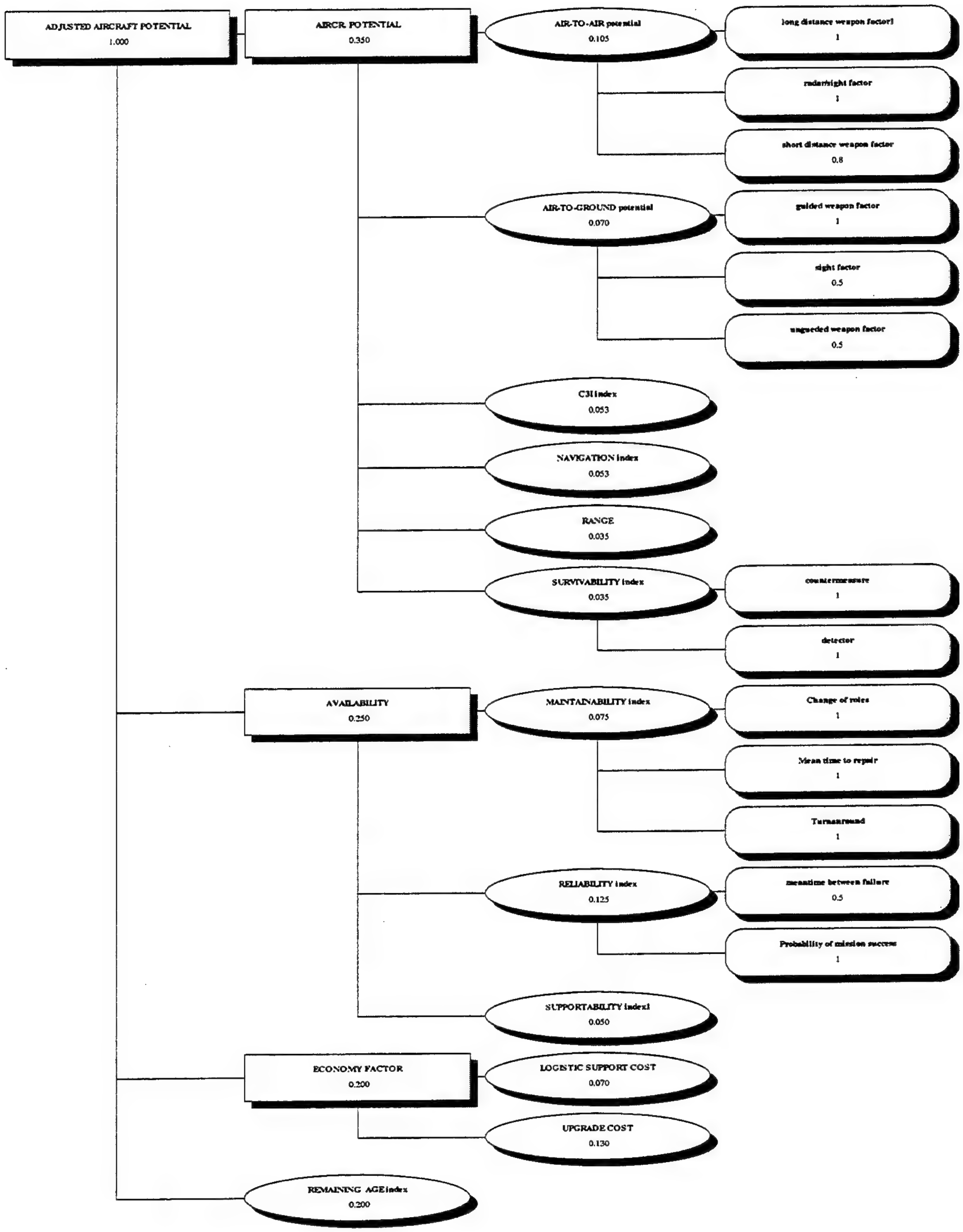


Figure 12. LDW Modernization Model Goals Hierarchy. Overall Weights.

D. THE RESULTS

Methodology selection demands a special approach to the comparison of the results. The main questions usually are, "What are the forms of the result? What does it mean? How is it sensitive to changes in inputs? Do both methods support similar decisions and prove initial hypothesis?"

1. The Form and the Meaning of the Results

The TASCFORM-Air model generates measures of effectiveness for individual aircraft. Figure (12) shows the table of results for individual levels: Weapon System Potential (WSP), Adjusted WSP and Designated AWSP.

							INTERCEPTOR AIRCRAFT MISSION
LAST UPDATE:	3/4/00	IMPAC		WSP@			
SYSTEM		CATEG	IOC	IOC	WSP00	AWSP00	DAWSP00
MiG -29S		INTP	1988	18.7	18.1	18.1	15.1
MiG -29"MD"		INTP	1988	18.5	20.3	20.3	17.0
MiG -29SMT		INTP	1988	21.9	28.5	28.5	23.8

Figure 13. TASCFORM-Air Model Individual Measures of Effectiveness

The TASCFORM-Air model compares a given aircraft with the basic aircraft (F-4B). It does not directly address the military utility of the basic or evaluated aircraft. The meaning of the TASCFORM scores is actually the rate that one is willing to substitute one aircraft to another in order to have the same mission efficiency. The score of the basic aircraft in the model is equal to 10. The results in Figure (13) show us that individual scores for MiG-29S/ MiG-29MD/ MiG-29SMT programs are rated as

18.1/ 20.3/ 28.5. This means, for example, that one MiG-29MD is equal to two F-4Bs in the interceptor role and one MiG-29SMT is almost equal to three F-4Bs.

Computing the measures of effectiveness of air forces (or any air force unit) is a two step process. First, a designated force potential score is computed. This score is the sum of scores of the individual aircraft performing a given role. (Timperelake, pp.. 2-3) Next, an equivalent force potential measure of effectiveness is computed by scoring relative obsolescence, multi-role capability, the effect of the numbers, C3I capabilities, logistic and personnel qualities.

Air force level indexes of effectiveness (Designated Force Potential and Equivalent Force Potential) have meaning only for a particular situation. In accordance with the model and the problem design it may be valuable for resource allocation tasks or

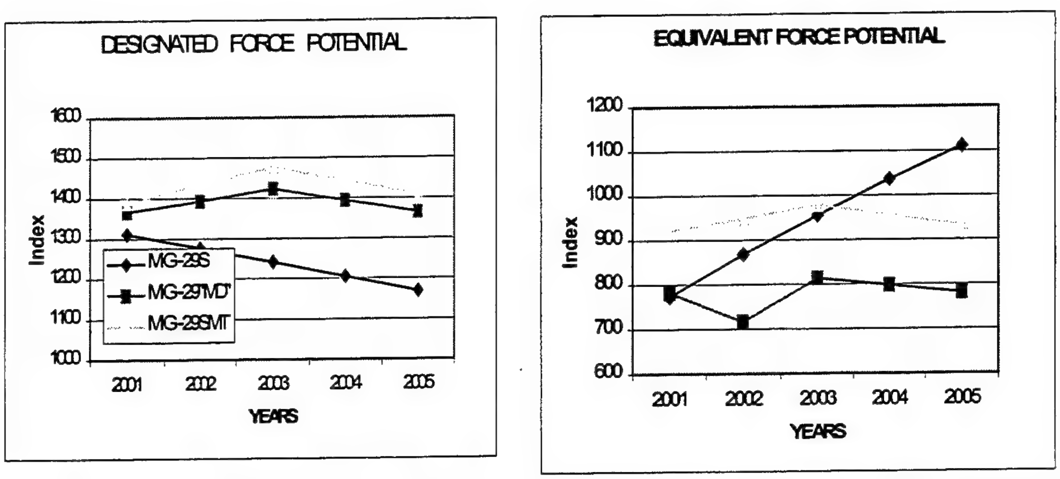


Figure 14. TASCFORM-AIR Model Force Level Measures of Effectiveness

rational force structure definition. Graphs of the force potential measures for MiG-29 modernization problem are given in Figure (14).

As we can see, TASCFORM AWSP and DFP scores for the MiG-29 modernization alternatives give preference to the SMT program, while the EFP shows that the training program by the end of a five-year period is 20% more effective than the "SMT" program. In our case it means that for the same money ($ 100 million), training gives 20% better result than modernization.

In contrast to the TASCFORM-AIR model, the LDW model provides only one set of results. It is the utility for assessed alternatives. LDW computes an alternative's utility by combining its measures level based on the analyst's preferences. The most common forms of the results are given in the Figure (15).

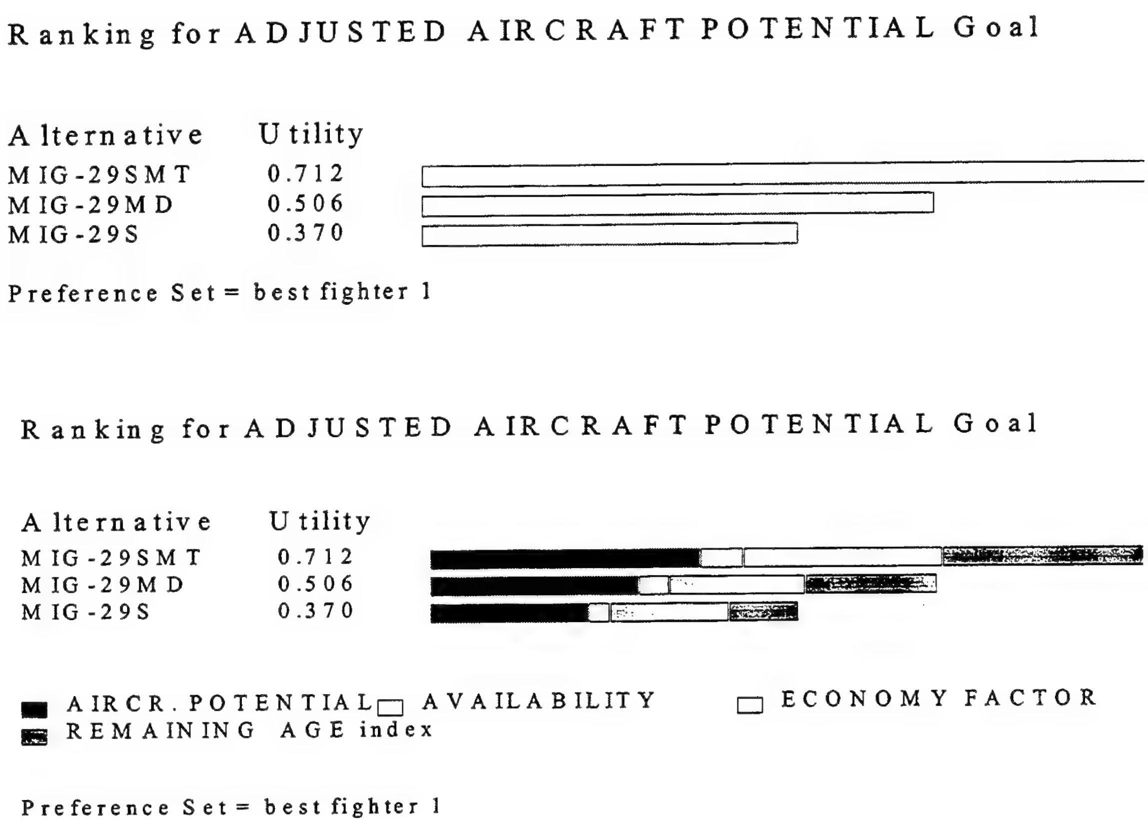


Figure 15. LDW Ranking of Alternatives

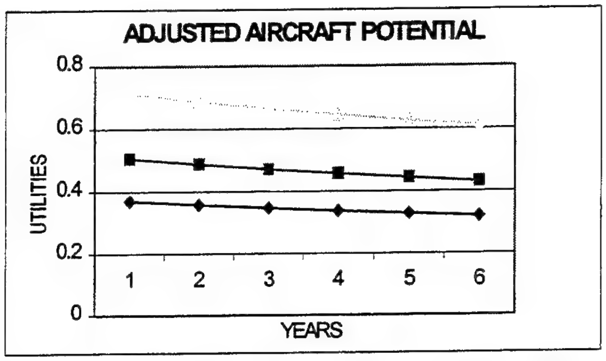


Figure 16. Graphs of the LDW Model Adjusted Aircraft Potential

Time can be incorporated in the LDW model, with separate program runs done for each year. Figure (16) shows the graphs for alternative utilities in a time perspective.

The advantage of LDW is a wide range of choices of methods to provide and to analyze the available results. There are sixteen different functions in the LDW result mode. It can be pure "rank alternative" or "stacked bar ranking" that show relative importance of each goal in the final result (Figure 14), or it can be diagrams or tables explaining the different aspects of the result.

In contrast to TASCFORM, LDW computes an interval scale. Changes in inputs give changes in utilities, and those changes can be compared. For individual aircraft we can compare changes in utilities from basic level (status quo) to the variable cost of modernization. Cost-utility ratio (CUi) for "SMT" and "MD" alternatives can be computed as :

CUi = (Ui – Uo)/ Ci, where;

Ui, Uo - Utilities of the assessed alternative and status quo;

Ci - Variable cost of the modernization program.

The force level indexes in the LDW model is based on the same data used for the inventory level and the crew proficiency, as was the case in the TASCFORM-AIR model. The LDW force level utilities are given in Figure (17).

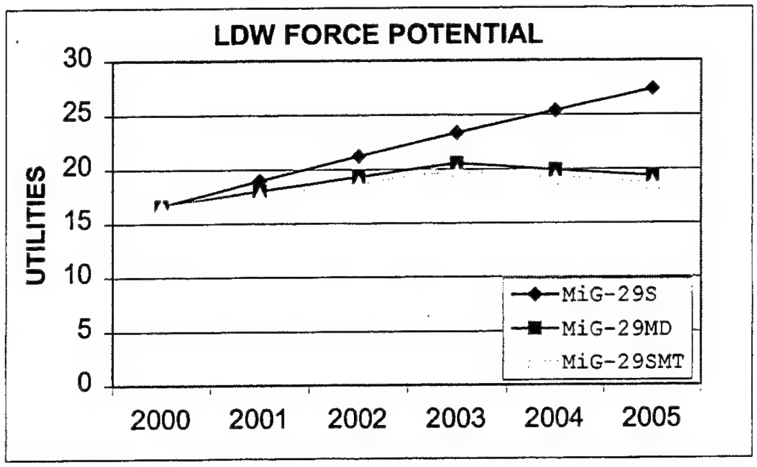


Figure 17. LDW Utilities for the Force Level

The LDW results are similar to the TASCFORM results at both the individual and at the force levels. Both models show that the training program is more effective at the force level, while at the individual level the "SMT" modernization program is significantly better than all the others. Actually these results prove our first hypothesis: If the level of crew proficiency is low – the investment in aircraft modernization (without intensifying training) is not the best.

The assessment of the budget influence led to a predictable conclusion: Every program has limited abilities to increase efficiency by intensifying training. From a given level of investment, additional training cannot produce additional efficiency. If the air forces have reached normative training level, the only way to increase the force potential

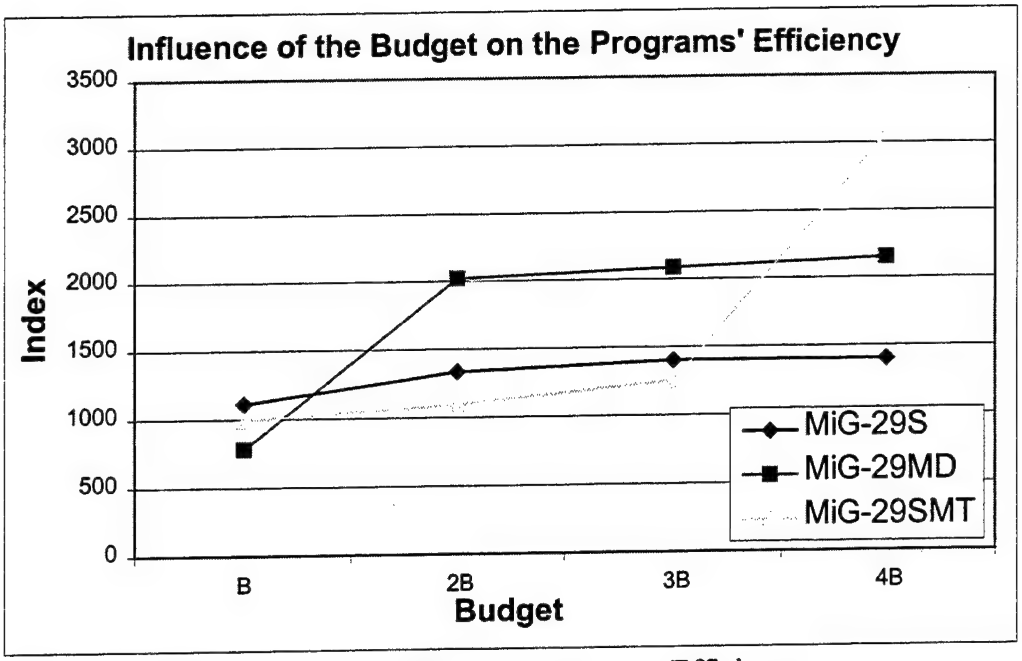


Figure 18. The Influence of Budget on Program Efficiency

is to increase the weapon potential. Figure (18) shows an equivalent force potential as functions of the budget.

This graph shows that the training programs actually have reached the maximum efficiency on the level of the initial budget. The assumption in the calculations of the budget influence is that at first money goes to modernization rather than to training. The next results show that doubling the budget increases the efficiency of the "MD" program by two times. But employing the "SMT" program with four times the initial will result in the highest efficiency rate possible in the situation.

In the modern high-competitive military environment, the price to improve efficiency is significant. Moreover, the initial choice of program will define the maximum achievable level.

2. Correlation of the Results

The correlation of the results for both programs is obvious. First, both methods have similar results at the individual weapon level. Second, they have the same tendencies in transition from one level to another. Finally, changes of similar parameters cause comparable changes in the results.

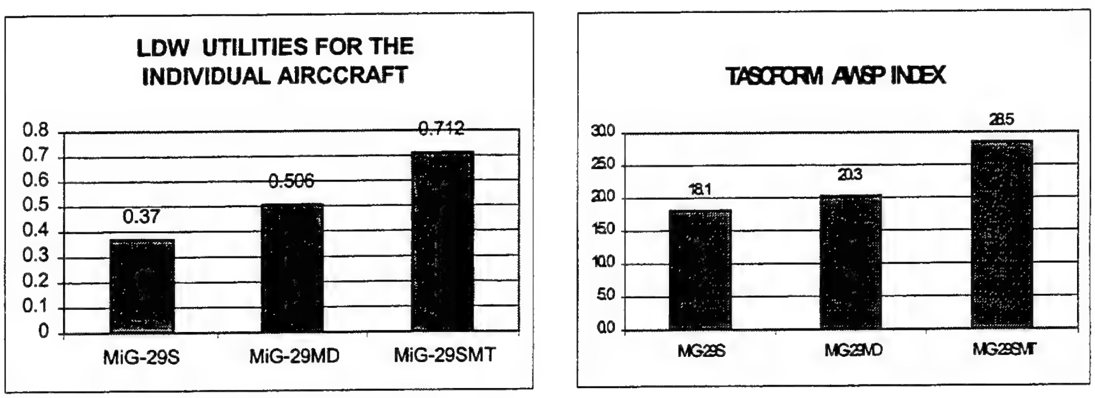


Figure 19. Comparison of the LDW and the TASCFORM Individual Indexes

Figure (19) shows the comparison of the LDW Adjusted Aircraft Potential (AAP) with the TASCFORM-AIR model Adjusted Weapon System Potential (AWSP).

The alternatives in both methods are ranked in the same order with similar ratio tendencies. The mutual ratios of the indexes are 1.92/ 1.36/ 1.00 for LDW and 1.57/ 1.13/ 1.00 for TASCFORM-AIR model. Differences in the ratio are most probably

caused by the initial approach to the problem. The LDW considers only the parameters that are influenced by modernization, while TASCFORM includes all the aircraft's performances. This makes the difference in the TASCFORM results less then the differences in the LDW results.

Both methods define training (MiG-29S alternative) as the best alternative in the force level of analysis. The second and third preferences are different. For example the TASCFORM approach evaluates "SMT" program 10% higher than the "MD" program, while the LDW gives 3% preference to the "MD" over the "SMT" alternative.

Attempts to analyze cost-utility and cost-effectiveness ratios for "SMT" and "MD" alternatives at the individual level led to controversial results. Figure (20) shows the results of the calculations.

Alternative	Cost-Utility Ratio	Cost-Effectiveness Ratio	
	Uo (MiG-29S)	Eo (MiG-29S)	Eo (F-4B)
SMT	0.114	**3.47**	6.16
MD	**0.136**	2.2	**10.3**

Figure 20. Cost-Utility and Cost-Effectiveness Ratios of Modernization Programs

When utilities of status quo (MiG-29S) were used as the basic for calculating the cost-utility ratio, the "MD" program had a higher ratio than the "SMT" program and is therefore more preferred. The same approach in the cost-effectiveness analysis gives the opposite result. Here the "SMT' program had a better ratio. With basic aircraft changes to the F-4B, this ratio once again favors the "MD" program. These results are good

illustrations of complexities in the decision-making process. Different indexes and even different concepts of efficiency may lead to different conclusions. In our models the "SMT" program has the best indexes at the individual level of analysis. The "MD" program has a better cost-utility and cost-effectiveness ratio. And finally, the training program has a better perspective in the force level.

3. Sensitivity and Reliability

Sensitivity analysis is an attempt to deal with uncertainty. Sensitivity analysis can be preformed with respect to both predictions of impacts and their valuation per unit of impact. In particular, it should convey how sensitive predicted indexes or utilities are to changes in assumptions. If the ordering of alternatives does not change when we consider the range of reasonable assumptions, then our analysis is robust and we can have greater confidence in its results.

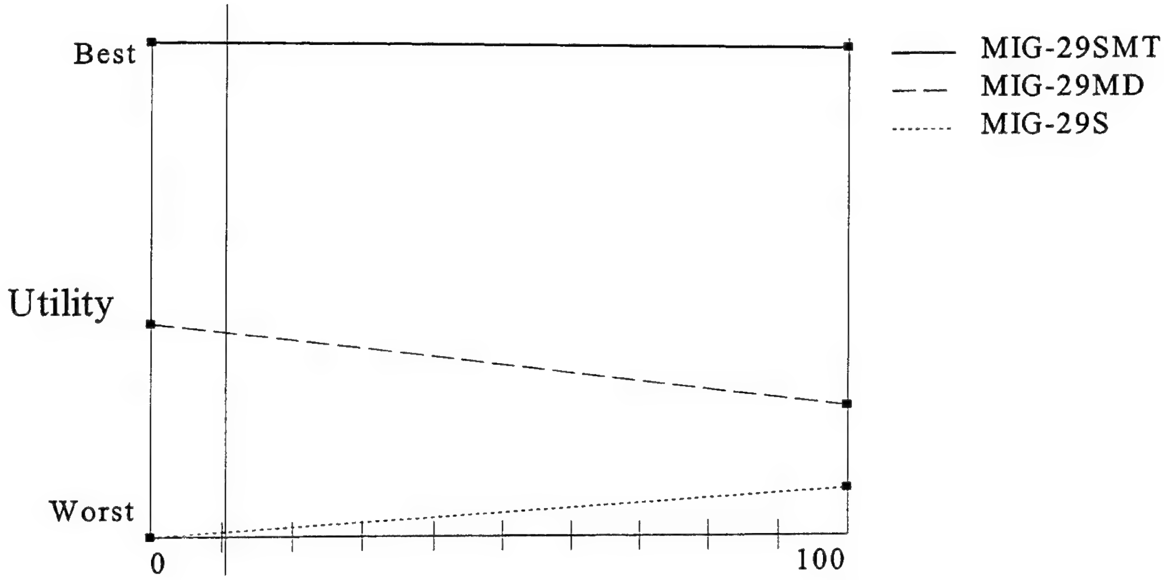
The results of a partial sensitivity analysis for TASCFORM-AIR model are given in Figure (21). Partial sensitivity is most appropriately applied to what the analyst believes to be the most important and uncertain assumptions. For porpoises of methodology comparison, I've conducted sensitivity analysis for both groups of the results in every method.

Compared to TASCFORM, the LDW has great built-in possibilities for sensitivity analysis. The "Sensitivity Graph" option let us see the effect of changing the weights of a single measure or goal. Sensitivity tables let us see the effects of the changes in weights of the goals and measures quickly. (Figure 22).

#	PERFORMANCES	CHANGE (%)	INFLUENCE ON FINAL INDEXES	
			AWSP	EFP
1	RANGE	+20	+2.5%	+2.0%
2	PAYLOAD	+20	+9.8%	+2.7%
3	SPEED	+20	+8.5%	+2.1%
4	MANEUVERABILITY	+20	**+21.5%**	+1.8%

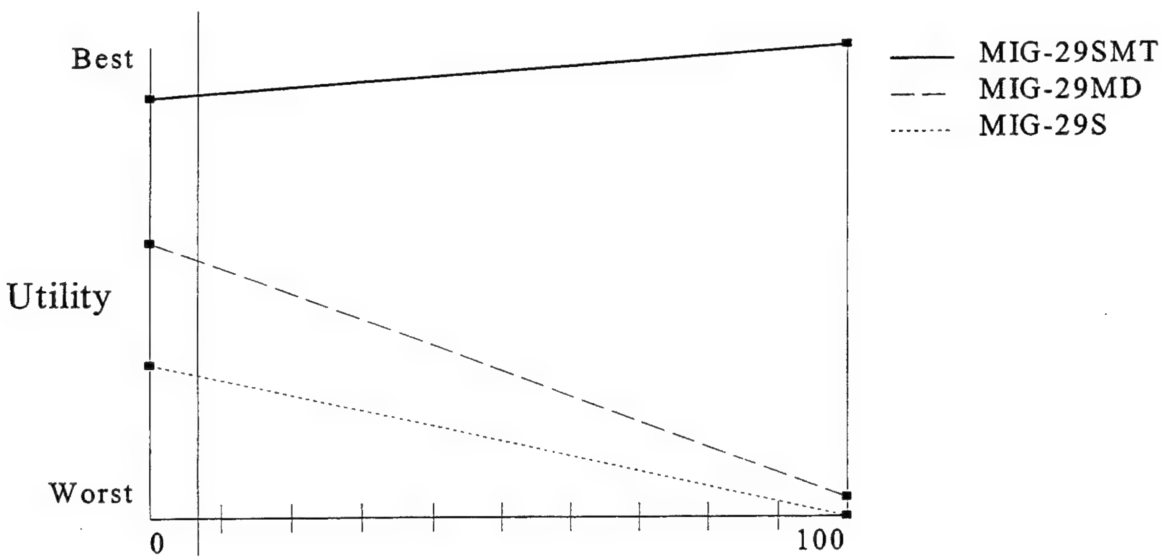
#	GOALS/ MEASURES WEIGHT. FACTORS	CHANGE (%)	INFLUENCE ON FINAL UTILITIES	
			PERFORM.	WEIGHT. FACTOR
1	Range/ WF	+20	+0.5%	+0.15%
2	Reliability/ WF	+20	+0.25%	**- 6.3%**
3	C3I / WF	+20	+1.0%	+1.6%
4	Remaining age/ WF	+20	+5.9%	+2.2%

Figure 21. The Results of the TASCFORM and the LDW Sensitivity Analysis



Percent of Weight on AIR-TO-AIR potential Measure

Preference Set = best fighter 1



Percent of Weight on AIR-TO-GROUND potential Measure

Preference Set = best fighter 1

Figure 22. LDW Sensitivity Tables

Reliability of the results in both methods depends on the quality of the initial data, the model validity and the quality of expertise. Nevertheless, both methods are useful for certain conditions and within the constrained data fields. For example, let us assume for both models that the meaning of the range and survivability of the "SMT" alternative is equal zero. In reality such an aircraft has no military value. But both of our models still assign positive indexes to it. (Figure 23) In practice this means that analysts using these methods should understand the nature of the problem and perform a pre-modeling data analysis. They need to exclude alternatives with invalid characteristics or modify the model to make it reliable. The LDW software has the possibility to include probabilities and uncertainties into the analysis. In this case we can estimate the reliability of the results numerically, but the results shift from interval to ordinal scales. This makes them impossible to use for valuable cost-utility ratios.

While the nature of the problem and the data available have certain levels of accuracy and reliability, every cost-effectiveness and cost-utility analysis should be subjected to tests of their sensitivity to the assumptions that they employ.

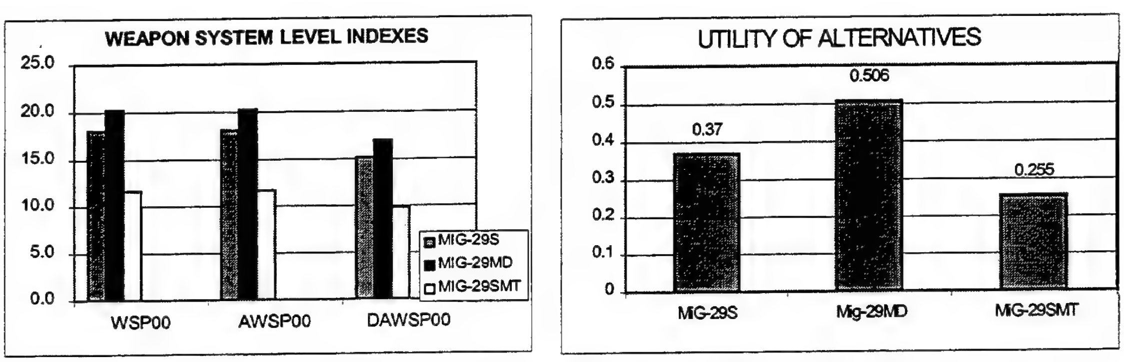


Figure 23. Indexes and Utilities of Alternatives When Speed and Range for "SMT" Alternative are Equal Zero

D. METHODOLOGIES

1. Basic Perspectives

Both the TASCFORM AIR Model and the LDW Model provide the dimensionless measures of the relative technological quality of a given system. Both employ utility functions, using subjective inputs to assign weighting factors to measurable attributes. In formulating the LDW Model, I assumed that analysts might use different methods to select the initial data. It may be Delphi approach that depends on the written survey data gleaned from experienced military users or from a simple expert estimations. TASC, on the other hand, created the TASCFORM-AIR model internally and had the preliminary version reviewed by tacair community representatives for comments on all subjective aspects. (Timerlake, pp.. 1-5)

The different methodological approaches and applications of the two models dictate different levels of details. By design, TASCFORM is a relatively simple model. This limits the volume and classifications of the data to be used. The LDW model based on the scenario at hand and on the level of detail included may use significantly smaller or greater data.

2. Outputs and Applications

Understanding of the TASCFORM-AIR model results for an individual weapon is simple. The score for the basic aircraft is 10, so if the assessed aircraft has scored 20, it means that this aircraft is equal to two basic aircraft for a certain mission. To understand

force level measures of effectiveness, the user should know the scenario. Due to the initial data, results may vary from hundreds to thousands. Particular results have meaning only for a comparison of the given alternatives in certain situation.

The LDW results are utilities scored in the interval from 0.0 to 1.0. In accordance with the scenario and methods used to quantify preferences, it has (in our case) an interval scale meaning.

The ability to generate scores to measure the potential of individual weapon systems (WSP, AWSP) and basic military organizations (EFP), and to modify these scores to take into account qualitative factors make TASCFORM useful in a number of ways. First, it is useful for doing systems analysis studies to track technology growth and cost performance trends. Second, it is useful to do macro-level force balance comparison for strategic and operational planning. Third it is useful for conducting net assessments of current and future military balances of any region in the world. (Cherniavsky, p. 4) TASCFORM and LDW results are intended primarily for the:

- Static comparison of the aircraft potential;
- Force potential input into probabilistic dynamic wargaming models;
- Input into force development and procurement decisions;
- Measurements of relative force modernization, principally at the total force level, defined as the differential of force equipment potential over time;
- Estimation of associated military investments, when TASCFORM outputs are coupled with appropriate cost data.

TASCFORM-AIR Model is able to generate tacair modernization rates. (Regan, p. 4-1) These are based on either Designated Force Potential (DFP) or Equivalent Force

Potential (EFP), depending upon whether the analyst chooses to assess the extent of the modernization embodied in a tacair force when incorporating synergetic factor.

Modernization rates for the period are calculated as follows:

AMRc= dDFP/dt = [(DFPi – DFPo)/DFPo] *100%

FMR = dEFP/dt = [(EFPi - EFPo)/EFPo] *100%

Where: AMRc- collective aircraft modernization rate;

FMR - force modernization rate.

The model thus provides the analyst with the means for assessing the effect of equipment modernization.

3. Form of the Utility Function

The TASCFORM-AIR Model has four basic additive parameters: payload, range, maneuverability, and useful speed to describe aircraft performance. The values used for this are actual performance figures normalized to baseline aircraft values. On-board systems and features modify these values multiplicatively, and survivability enters as a multiplicative modifier of the entire weapon system measures of effectiveness (MOE) rather than as an additive term. Individual aircraft MOEs are adjusted for relative obsolescence and productivity prior to being multiplied by inventory levels and summed to determine the basic force MOE. This is then adjusted by factors reflecting the impact of changing force levels, C3I, and multi-role capability.

The presented LDW Aircraft Modernization Model is based on three basic additive goals: aircraft potential, crew potential, and economy factor. Each of these is an

additive function, which incorporate as many as ten measures and ten more measure categories. All measures and measure categories are subjectively measured. The LDW utilities for the Adjusted Aircraft Potential are determined by converting given measures to common units (utilities) and establishing the relative importance of the goals and measures. To receive an index (FPI) comparable with the TASCFORM Equivalent Force Potential, one can multiply the AAP by the inventory level.

4. Scenario Applicability

The TASCFORM and the LDW approaches are consistent in the area of scenario applicability. While the generic TASCFORM methodology was deliberately developed with no specific scenario in mind, it had always been recognized that tailoring the weighting factors to fit a given scenario is an appropriate application of TASCFORM. This is regarded as one of the virtues of the model. (Cherniavsky, p. 5) Similarly, different LDW models can be generated using specific scenarios, simply by adjusting goal hierarchy and preferences as appropriate.

5. Treatment of Intangibles and Design Obsolescence

The basic LDW methodology may include consideration of human factors and intangibles in its models. Obsolescence may be expressed as usual utility with negative utility function. The given model results are time–specific only in the sense that an updated set of scores reflects the consensus of the study group at the time of the update, and changes may be manifested in a revised subjective weighting schedule. We can

conclude that score for the same aircraft generated in different modifications of models should not be compared for analytical purposes.

TASCFORM also contains, albeit in rudimentary form, consideration of some intangible aspects of force modernization, such as supportability and maintainability of systems, the effects of embodying greater quality in fever systems, and vice versa. In addition, it contains the effect of building multipurpose versus specialized systems, the effect of aircrew and groundcrew proficiency, the effect of improved force command, communication and control, and design obsolescence. The fact that all of these aspects change over time is accounted for, and that will enable the TASCFORM user to compare the effects on individual systems over time, as well as to assess force-level trends in modernization.

6. Enhanced Assessment Capabilities

The given examples of methodology use are limited to weapon system potential and theoretical aggregate force potential. In many cases of military related planning and analysis these indexes are not sufficient. Determining real force potential requires assessing the intangible non-weapon aspects of a military force. The Analytic Scientific Corporation has developed a set of companion models to measure the following (Regan, pp.. 1-2):

- C3I systems;
- The potential of available manpower to operate and maintain a force's weapon systems;

- Effects of logistic organization, support, and sustainability on overall force potential;
- Ability to mobilize and deploy a force's assets;
- Force structure and resource (fiscal) allocations;
- Modernization through technology development.

Compared to TASCFORM methodology, the LDW is a more universal tool. It helps analysts evaluate any decision quantitatively. One should define all alternatives and variables to describe them. After that, LDW helps to formulate preferences about the variables and uses the information to rank alternatives. So the main difference is that TASCFORM is a set of exact algorithms to be used in specific areas, while the LDW is universal methodology to build different algorithms. In both methodologies, the quality of results depend on the quality of initial data and assumptions. TASCFORM models are likely to be used widely by the public, because all the expert's estimations are included, while the LDW models are strongly dependent on the quality of "in-house" expertise.

F. LIMITATIONS

All analytical models have limitations. TASCFORM and LDW are static assessment models and have many of the limitations of static models. Both models are not predictors of combat outcomes. They are indicators of force potential. In given forms and programs' design both models do not account for dynamic interactions and cannot measure the synergy between and among systems in combat.

It was recognized early that the availability of data concerning aircraft performance and qualities may vary significantly for different modernization programs. The limit of methodological details in both models let to the development of *relative* indexes of aircraft and force potential, not an attempt to create unnecessarily precise *absolute* values.

G. SUBJECTIVE FACTORS

Several areas within modernization decision process are influenced by organizational and individual subjective factors. The most obvious factors are the methodology selection, the collection of the initial data, the assigning of weighting factors, and finally the subjective political preferences. Therefore, different methods may give different results, so the methodology selection plays a certain role in the decision making process. In the real world, it is often a matter of competition between scientific or research institutions for resources and programs. In our case the TASC Corporation has more authority, experience and contacts within the MOD. This organization promotes and advertises its products at all levels of MOD organizations. It may indeed influence MOD decisions more than any new scientific company just in the market. On the other hand, the more methods are used for the assessment, the less is the probability of mistakes.

The selection of the initial data also may influence the final decision. It is clear that organizations representing modernization programs will collect and present selected data to show their product in a good light. In this case, the strict and stable TASCFORM

Air Model is less influenced by the initial data than the LDW models constructed for a particular problem. But data collected from independent sources (if available) may eliminate this problem. Weighting factors are the most important and most subjective part of both the TASC and the LDW methodologies. The TASCFORM Air Model includes 12 individual weighting factors, while the presented LDW model consist of 17 expertly assigned utilities, 10 category multipliers, and 17 SUFs. All these numbers represent the expert's estimations of data, the relations or the relative importance of any presenting factors.

TASC emphasizes that their weighting factors are the result of a series of conferences, seminars and meetings where a wide spectrum of military scientists, pilots, engineers and operational planners had made their estimations. These estimations were later statistically transformed to weighting factors present in the model. Reliability of any model based on expert judgement is a function of the number and qualities of experts participating in creating the model. One more significant factor, which influence military decisions, is the political preferences. This becomes very important in case of selections between domestic and foreign armament. Below are the results of a short questionnaire among the Naval Postgraduate School international and US students concerning their personal preferences in armament acquisitions. Two questions were posed:

- Assume that you are the member of a committee for acquisition source selection. In particular situation you have three choices: (Select one)

  - *To buy domestic weapon;*

  - *To buy 30% more effective foreign weapon at the same price;*

- *To postpone acquisition for five years and to invest the money in R&D with a 60% probability of creating an equaled weapon in the future.*

- When would you prefer armament produced in a foreign country? (Give both figures)

  - *Armament produced by allied country is _____ more effective than domestic.*

  - *Armament produced by a non-allied country is _____% more effective than domestic.*

Figure 24. Distribution of Responces for Qestion 1

(A-Buy domestic; B- Buy 30% more effective foreign; C- Invest in R&D.)

The results of this questionnaire are given in Figures (24) (25).

From the diagrams we can conclude that weapons that are produced by allied foreign countries should be 20% more effective in order to be equally preferred to the domestic ones, and 50% more effective if produced by non-allied countries. Reliability of these results is not very high because of the small number of participants, but the common tendency is obvious: political preferences have a strong influence on any military decisions.

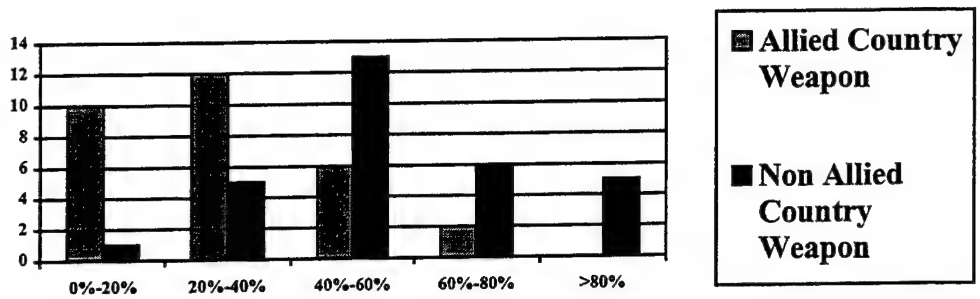


Figure 25. Distribution of Responses for Question 2
(Level of effectiveness for foreign weapon to be preferred to domestic.)

V. CONCLUSIONS

Making a decision is like playing Mozart on the piano: it is easy to do, but hard to do well. (Brenesal, p. 1)

In today's corporate world and bureaucratic environment, making a good decision in a timely fashion is essential. However complex alternatives, uncertainties, and varying goals and preferences render this difficult – and a decision once made, can be nearly impossible to explain to people not involved in the decision-making process Methodologies, which are assessed in this thesis, allow decisions based on quantitative analysis. They also help to understand and to explain the decisions being made. These methodologies are intended to bring clarity to the evaluation process.

The TASCFORM and the LDW methodologies have much in common. Both employ utility functions, rely on subjective inputs, and can address different scenarios. The differences stem from a fundamental divergence in the approaches to aggregating various system attributes. In the TASCFORM approach, the physical performance parameters such as range and payload are considered to be the basic, additive parameters that establish the system's weapon potential. These basic characteristics are then modified by on-board system capabilities, which enlarge or diminish the significance of those physical performance parameters multiplicatively. In the LDW approach, on-board system capabilities are part of the goal called "combat effectiveness." Their utilities are added to a common function in accordance with the individual SUFs and preferences. In the TASCFORM, survivability features are represented by another multiplicative term,

which adjusts the overall "productivity" of the weapon system. In the LDW approach, it is a separate measure expressed only by countermeasure utilities just because the rest of the factors, which influence survivability, didn't change in the modernization of the MiG-29.

There are possible differences caused by the strictly non-linear translations of performance capabilities into additive component indices in the LDW approach.

This does not imply, of course, that there is no correlation between LDW and TASCFORM. The rank ordering of the alternatives, for instance, is the same with the LDW or the TASCFORM. Both approaches consider virtually the same set of weapon system attributes and grant them generally the same order of importance. The difference is that the range in the indexes between the most and least capable aircraft is 1.9:1 by the LDW, but only 1.57:1 by the TASCFORM

The TASCFORM-AIR Methodology does not consider cost as input, so the measures of effectiveness are not synonymous with cost-effectiveness. However, it should be noted that force level measures of effectiveness for a given air unit are subsequently multiplied by the number of that aircraft's inventory at a selected time to derive its contribution to an overall force measure of effectiveness. Those inventory levels are related to system costs, thus introducing a second order cost effect in the model.

The TASCFORM-AIR model requires knowing a large number of physical parameters. The weighting factors and constants for the main tactic aircraft missions are included in the methodology. It is a well-developed model with a comparatively specific

application range. It makes this method easy to use by any specialist in any level of military planning. Because the model is framed, the analyst has to adjust the situation to the model.

The LDW methodology requires a good understanding of the problem at hand and a high level of expertise in order to create structure (the goal's hierarchy) and to define preferences. The absence of the strict framework gives wide possibilities, but demands experience and accuracy. LDW is a highly adaptive tool based on multi-attribute utility analysis that is good enough to be used in most decision support systems. This method, in contrast to the TASCFORM, may be adjusted to any situational model.

The results produced are useful in several ways, but as indicators rather than as "answers." First, the quality/quantity index values for weapon systems and forces can be used to analyze the effects of technology growth and modernization measures on the conventional force potential. These can then be compared to similar indicators to assess ranges of uncertainty regarding these trends. Second, the index values are quickly generated and the system can therefore be rapidly reprogrammed to generate alternative models based on different performance assumptions. This ability to offer comparisons of the effect of different perceptions is useful in suggesting directions for more detailed analyses using more complex simulation models and techniques.

It is important for an analyst to reflect the effects of product improvements, given the extent to which modifications such as electronic countermeasures, improved munitions and new navigation systems have been added to existing weapon systems.

TASCFORM caters to this and can depreciate quality indexes with time in the absence of improvements to reflect the relative decline in potential of older weapon systems.

The form of the TASCFORM results is more convenient and understandable for the user. It has the ratio meaning and can be easily used to compose different indexes. The understanding of the LDW resulting utilities is more complex. In accordance with the applied forms for the single utility functions and applied methodology of preferences, utilities may have either an interval or an ordinal meaning. This fact makes the LDW utilities difficult to use in the cost-utility ratios.

We have to mention here that both methods support the initial hypothesis. In situations with insufficient pilot proficiency, relatively small investments should be spent on training, while a large investments should be directed to training combined with the best modernization program available.

Sensitivity analysis shows that LDW methodology is less sensitive to the partial changes in inputs than the TASCFORM.

The areas of application for both methodologies are approximately the same. The main difference lies in the level of expertise required by the methods.

Static quality/quantity methodologies do have some limitations. For example TASCFORM has been designed for simplicity and ease of use. Complex processes and interrelationships have been represented by simplified characterizations of typical outcomes. The reliance on subjective inputs makes both methodologies only as good as the judgements that have been incorporated. Care has been taken to ensure the quality and objectivity of these inputs. Most importantly, static force assessment methodologies

are not useful in predicting combat outcomes. Their utility lies in shedding light on the correlation of military forces through side-by-side comparison of conventional force elements and associated trends.

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VI. RECOMMENDATIONS

The real modernization decision-making will take place in a dynamic context political environment, developing of the force structure and the ongoing military force modernization of in all of Ukraine's neighboring countries. This will demand careful analysis. A variety of flexible analytical tools must be used whose results must be integrated. These tools range from simple static analyses ("the bean count"), through more sophisticated force quantity/quality indexes, to the full range of dynamic techniques, such as simulations and war games. However, several cautions are in order. (Vogt, p. 1)

First, no single technique or small set of techniques can provide the "correct" answer; each has its own advantages and drawbacks. An understanding of air force capabilities requires the integration of outputs from a number of indicators, as in economic analysis. Economic analysis is a complex field that has produced a broad range of static and dynamic analytical and predictive techniques. Different theoretical perceptions of the overall process have resulted and a substantial degree of uncertainty remains. The same is true of net assessment of any air forces.

Second, any comprehensive analysis must acknowledge that the participants will disagree about the main features of the air forces modernization program, due to the political concerns and attempts to obtain an advantage by exaggerating the potential problems of the particular service. Thus, the same analyses need to be applied to

different sets of data, and the results examined to see whether the disagreements have a significant effect on the overall assessment of the alternatives. (Vogt, p. 2)

Cost containment is not always synonymous with improved military capability. In conditions of insufficient financing achieving the highest possible benefit from the investment is critical for military programs. Quantification of the value of the military benefits of different modernization programs, is seen as an increasingly important process and is central to the role of the MOD Armament Department.

Providing advice on cost-effectiveness and cost-utility analysis in the MOD would involve the interpretation of an economic evaluation conducted from the perspective of the military benefits (readiness, sustainability, etc) provided by the modernization program. Budgetary limits make economic evaluations more useful and acceptable, as often a new weapon may have higher costs while reducing expenditure in other sectors of defense by reducing personnel or maintenance cost. The aim of economic evaluation is to determine how available resources can be used most efficiently. All economic evaluations must satisfy two criteria to qualify as full economic evaluations. There must be:

- Comparative analysis of two or more alternatives;
- A full exploration in all cases of both the costs (and inputs) and the consequences (or outcomes).
- All economic analyses should comprise the following three dimensions:
- The type of analysis;
- The perspective of the analysis;

- The type of costs that are included.

Types of analysis. There are three main types of full economic analysis: cost-effectiveness analysis, cost-benefit analysis and cost-utility analysis. All show the economic efficiency associated with a particular course of action compared to an alternative course of action. All these methods measure costs in monetary terms, but they differ in how outcomes are expressed.

The perspective of an analysis is an important concept and one that must be stated at the outset of a study. The perspective defines the range of costs and outcomes that must be included in the analysis. If it is not stated it is impossible to tell whether all relevant costs and consequences have been discussed.

Practical hints. Always look very carefully at the literature and ask the following basic questions when you see a claim that a military program is "cost-effective":

- Has an economic evaluation been carried out?
- Was there a comparison of the costs and outcomes of the military program?
- Was there a comparison of at least two or more appropriate alternatives?
- What type of analysis was used?
- Was it appropriate?

Finally, each individual must come to his own conclusions about how much credibility the results have and how strong the arguments are that have been made in the analysis.

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APPENDIX A. TASCFORM-AIR MODEL METHODOLOGICAL OVERVIEW

The TASCFORM-AIR model generates measures of effectiveness individual aircraft and for tactical air forces. The model includes all principal combat aircraft whose primary function is to deliver conventional ordinance against air and surface targets. It does not include reconnaissance, ECM, FAC, and AEW aircraft. Those aircraft are included in the TASCFORM-C3I model. The model uses two broad roles for analysis purposes: air combat and face attack. Within each role are a number of functions or missions, as shown in Table 1.

AIR COMBAT	SURFACE ATTACK
Fighter	Close air support Heavy Bomber battlefield air Interdiction (CAS/BAI) launcher (ASM)
Interceptor	Interdiction Antiship cruise Attack helicopter missile (ASCM) launcher Heavy bomber Heavy air-to-surface missile (ASM) launcher

Table 1. TACAIR Roles

Computing the measure of effectiveness for a single aircraft is a three-step process. First, a weapon potential score is computed by scoring the airframe, power plant, and payload characteristics and normalizing that score against a baseline aircraft, the U.S. FIB. Subjective weighting factors assign relative importance to the characteristics depending on how they contribute to the air combat or surface attack role. In cases where a new model of an existing aircraft possesses a significant change in capability, that model is treated as a separate aircraft. Next a weapon system potential score is computed by scoring on board systems, such as weapons, navigation, and

avionics. Finally, an adjusted weapon system potential score is computed which scores relative productivity and the existence of an adaptive enemy. The adjusted weapons system score can be modified by a relative obsolescence factor to generate a depreciated score if desired.

Computing the measure of effectiveness of air forces is a two-step process. First, a designated force potential score is computed. This score is the sum of scores of the individual aircraft performing a given role. Next, an equivalent force potential measure of effectiveness is computed by scoring relative obsolescence, multirole capability, and the effect of numbers, C3I capabilities, logistics, and personnel quality. The method of computing measures of effectiveness for individual aircraft and air forces is summarized bellow:

WEAPON POTENTIAL (WP) - Basic system measure of effectiveness reflecting:

- Payload
- Aircraft range, basing modes, and standoff weapon range
- Maneuverability
- Speed

WEAPON SYSTEM POTENTIAL (WSP) - Adjusts WP for:

- Target acquisition and guidance/fire control
- Susceptibility to countermeasures
- Weapon enhancements
- Navigation

- Survivability

ADJUSTED WEAPON SYSTEM POTENTIAL (AWSP) -- Includes:

- Obsolescence*
- Productivity

DESIGNATED FORCE POTENTIAL (DFP) -- Basic force level measure of effectiveness considers:

- Distribution of assets to TACAIR roles
- Inventory levels

EQUIVALENT FORCE POTENTIAL (EFP) -- Adjusts for:

- C3I system effects
- A aircrew proficiency
- Logistics and maintenance
- Multi-role capability
- Tactical impact of inventory changes

*Can be included to produce depreciated measures of effectiveness or excluded at the analyst's discretion

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APPENDIX B. TASCFORM MIG-29

SYSTEM POTENTIAL LEVEL

FIGHTER AIRCRAFT MISSION							
LAST UPDATE:	3/4/00	IMPAC		WSP@			
SYSTEM		CATEG	IOC	IOC	WSP00	AWSP00	DAWSP00
MiG -29S		FGHT	1988	20.3	20.0	20.0	16.8
MiG -29"MD"		FGHT	1988	20.4	20.1	20.1	16.8
MiG -29SMT		FGHT	1988	24.5	24.2	24.2	20.2

INTERCEPTOR AIRCRAFT MISSION							
LAST UPDATE:	3/4/00	IMPAC		WSP@			
SYSTEM		CATEG	IOC	IOC	WSP00	AWSP00	DAWSP00
MiG -29S		INTP	1988	18.7	18.1	18.1	15.1
MiG -29"MD"		INTP	1988	18.5	20.3	20.3	17.0
MiG -29SMT		INTP	1988	21.9	28.5	28.5	23.8

PLNORM	RNORM	MNORM	VNORM	FPL	FR	FM
8	1800	122	1390	3	2	3

DSGN00	PL # AIR TO AIR STA	Rng km	Msl Rng LRAAM > 100km	BSFACT	USEFUL AIRSPD V (kph)	T(kg-force) ENTER TOTAL T * 101.9716	MAX T/O WT W (kg)
0.50	6	1500	0	0	2,440	16601.0	18,000
0.50	6	1500	0	0	2,440	16601.0	18,500
0.50	8	2100	110	0	2,440	18300.0	19,150

PLNORM	RNORM	MNORM	VNORM	FPL	FR	FM
8	1800	92	1390	4	3	1

DSGN00	PL # AIR TO AIR STA	Rng km	Msl Rng LRAAM > 100km	BSFACT	USEFUL AIRSPD V (kph)	T(kg-force) ENTER TOTAL T(kN) * 101.9716	MAX T/O WT W (kg)
0.50	6	1500	0	0	2445.0	16601.0	18000
0.50	6	1500	0	0	2445.0	16601.0	18500
0.50	8	2100	110	0	2445.0	18300.0	19150

FV	STOL	SEAPLANE	CARRIER	VSTOL	TFNGM	TFGM	TADAY	TANITE
2	450	450	750	200	0.2	0.8	1.0	1.0

TA1-00	GME1-00	CMGM1-00	N1-00	TA2-00	GM2-00	CMGM2-00	N2-00	TANGM00
2.0	1.6	1.0	4	2.0	1.2	0.9	2	1.0
2.0	1.6	1.0	4	2.0	1.2	1.0	2	1.0
2.0	1.6	1.1	4	2.0	1.2	1.0	4	1.0

FV	STOL	SEAPLANE	CARRIER	VSTOL	TFNGM	TFGM	TADAY	TANITE
2	450	450	750	200	0.1	0.9	1.0	1.2

TA1-00	GMEF1-00	CMGM1-00	N1-00	TA2-00	GM2-00	CMGM2-00	N2-00	TANGM00
2.0	1.6	1.0	2	1.2	1.4	0.9	4	1.0
2.0	1.6	1.1	2	1.2	1.4	1.0	4	1.0

TALWX	TAAWX	GMVSEMI	GMVHOME	GMVMULT	GMVOBS	GMBSEMI	GMBHOME	GMBMULT
1.2	2.0	0.8	1.0	1.2	1.4	0.8	1.2	1.6

NUMBER OF N/GUIDED SYSTEMS	WE00	ENTER CR CE3 TO CG3 NAV	SURVIVABILITY FACTORS, AIR COMBAT ENTER VALUES FROM TABLE PS/RC	VELOCITY	SIZE	SMOKE	ACTCM	PASSCM
1	1.2	1.0	35	25	15	10	0	5
1	1.2	1.0	35	25	15	10	0	5
1	1.2	1.0	35	25	15	10	0	5

TALWX	TAAWX	GMVSEMI	GMVHOME	GMVMULT	GMVOBS	GMBSEMI	GMBHOME	GMBMULT
1.6	2.0	0.8	1.0	1.2	1.4	1.0	1.6	2.0

NUMBER OF N/GUIDED SYSTEMS	WE00	ENTER CR CE3 TO CG3 NAV	SURVIVABILITY FACTORS, AIR COMBAT ENTER VALUES FROM TABLE PS/RC	VELOCITY	SIZE	SMOKE	ACTCM	PASSCM
1	1.2	1.0	10	25	15	10	5	10
1	1.2	1.0	10	25	15	10	10	10
1	1.2	1.0	10	25	15	10	15	15

GMBGMUL	CMVHI	CMHI	CMAVG	CMLO	CMVLO	NAVPOOR	NAVGOOD	NAVEX
2.0	0.7	0.8	0.9	1.0	1.1	0.8	1.0	1.0

						ALGORYTHMS
FIRE/FORG	STANDOFF	HARDEN	REDUN	ENTER CR CI3 TO CK3 SORTIE	A00	PLTERM
10	10	10	5	1.0	1	2.3
10	10	10	5	1.0	1	2.3
10	10	10	5	1.0	1	3.0

GMBGMUL	CMVHI	CMHI	CMAVG	CMLO	CMVLO	NAVPOOR	NAVGOOD	NAVEX
3.0	0.7	0.8	0.9	1.0	1.1	0.8	1.0	1.0

						ALGORYTHMS
FIRE/FORG	STANDOFF	HARDEN	REDUN	ENTER CR CI3 TO CK3 SORTIE	A00	PLTERM
15	20	10	5	1.0	1	2.3
15	20	10	5	1.0	1	2.5
20	20	10	5	1.0	1	3.0

DRAG	SRLO	SRAVG	SRHI	K	Uls	Ulmd	ULsmt
0.8925	0.8	1.0	1.2	2.0	20.0	25	30

					ALGORYTHMS		
RTERM	Ps	MTERM	VTERM	PU00	RAWSIGMA	SURV	AP
1.7	241	5.9	3.5	3.0	125.0	1.1	13.4
1.7	235	5.8	3.5	3.1	125.0	1.1	13.2
2.6	250	6.1	3.5	3.1	125.0	1.1	15.2

DRAG	SRLO	SRAVG	SRHI	K	UL
0.9192	0.8	1.0	1.2	2.0	25.0

					ALGORYTHMS		
RTERM	Ps	MTERM	VTERM	PU00	RAWSIGMA	SURV	AP
1.7	242	6.0	3.5	2.2	125.0	1.1	13.4
2.0	235	6.1	3.5	2.4	130.0	1.2	14.1
2.6	251	6.2	3.5	2.7	145.0	1.4	15.3

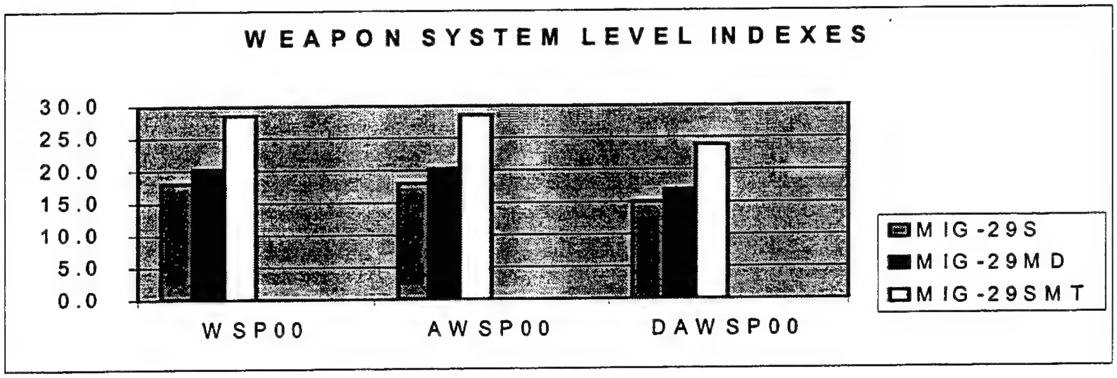
	EQIVALENT FORCE POTENTIAL					
	YEARS					MEAN
	2001	2002	2003	2004	2005	AWSPS
MiG -29S	1310.629	1276.135	1241.008	1205.206	1168.679	19.05382
MiG -29"MD"	1366.746	1392.761	1422.805	1394.156	1365.109	20.2
MiG -29SMT	1388.216	1432.409	1477.181	1443.263	1408.756	26.33201

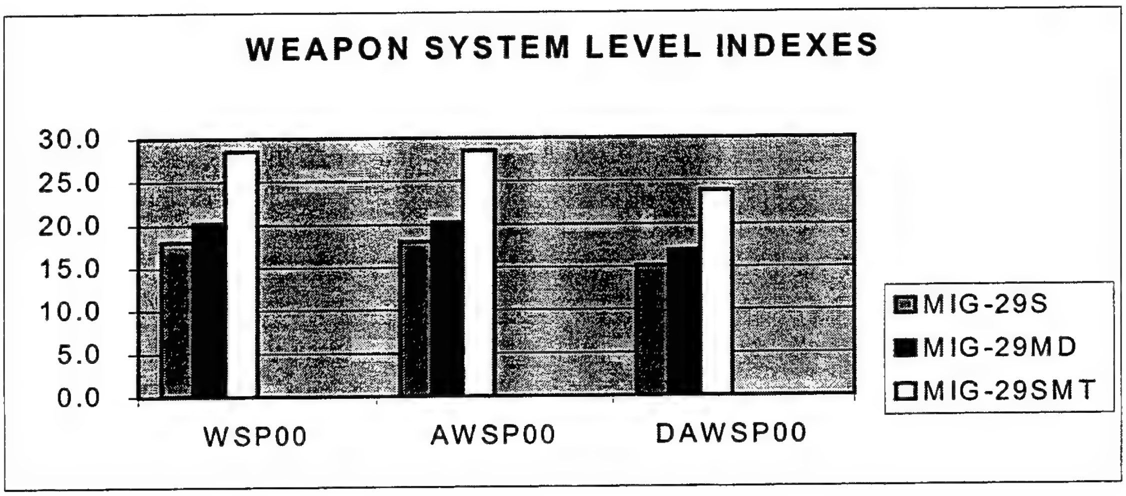
DESIGNATED FORCE POTENTIAL					INVENTORY				
YEARS					LEVEL				
2001	2002	2003	2004	2005	2001	2002	2003	2004	2005
773.2712	867.772	955.5764	1036.477	1110.245	90	90	90	90	90
781.7789	716.9934	813.8443	797.4572	780.8424	30.0	60.0	90	90.0	90.0
919.5543	948.8277	978.4847	956.0174	933.1601	10	20	30	30	30

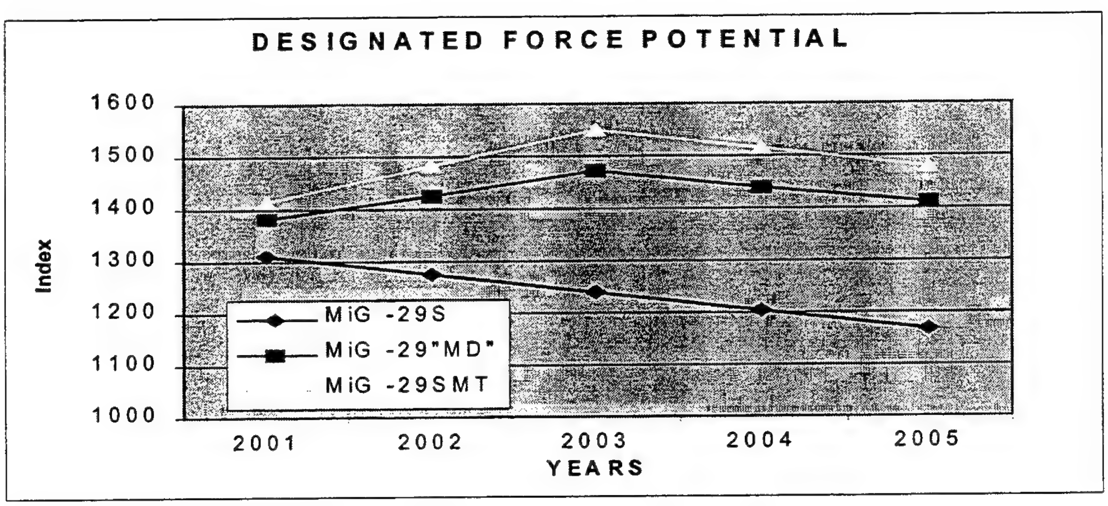
COEFFICIENTS				
Kc3i	Kmrc	Logistic	Maintenance	Ground crew
1	1	1	1	1
1.3	1.0	1.0	1.1	0.8
1.15	1.2	1	1.2	0.8

Air Crew Proficiency				
2001	2002	2003	2004	2005
0.59	0.68	0.77	0.86	0.95
0.5	0.5	0.5	0.5	0.5
0.5	0.5	0.5	0.5	0.5

Obsoletness				
2001	2002	2003	2004	2005
0.764285	0.74417	0.723686	0.702808	0.681508
0.815009	0.799631	0.784053	0.768265	0.752259
0.847684	0.835218	0.822626	0.809905	0.797049


WEAPON SYSTEM LEVEL INDEXES
30.0
25.0
20.0
15.0
10.0
5.0
0.0
WSP00
AWSP00
DAWSP00
MIG-29S
MIG-29MD
MIG-29SMT


WEAPON SYSTEM LEVEL INDEXES
30.0
25.0
20.0
15.0
10.0
5.0
0.0
WSP00
AWSP00
DAWSP00
MIG-29S
MIG-29MD
MIG-29SMT


DESIGNATED FORCE POTENTIAL
Index
1600
1500
1400
1300
1200
1100
1000
MiG -29S
MiG -29"MD"
MiG -29SMT
2001
2002
2003
2004
2005
YEARS

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APPENDIX C. MULTI-ATTRIBUTE UTILITY THEORY

Multi-Attribute Utility Theory (MAUT) applies to situation with uncertainty and multiple, often conflicting, objectives. For situation where the decision variables are independent, a weighted addition of utilities (i.e., linear) is used to produce an ordinal ranking of alternatives. When interactions between the variables exist, multiplicative terms are introduced, resulting in a multi-linear overall utility function. A general form of this equation is:

$$u(x) = \sum_{i=1}^{n} k_i u_i(x_i) +$$

$$\sum_{i-1}^{n}\sum_{j>1} k_{ij} u_i(x_i) u_j(x_j) + \sum_{i=1}^{n} \sum_{j>i}\sum_{e>j} k_{ij1} u_i(x_i) u_j(x_j) u_1 x_1 + \ldots +$$

$$k_{123....N} u_i(x_i) u_2(x_2) \cdots u_n(x_n)$$

where:

1. u is normalized by $u\ (x_1^0, x_2^0, \ldots\ x_3^0) = 0$ (the least preferred level of all measures) and $u\ (x_1^*, x_2^*, \ldots\ x_3^*) = 1$ (the most preferred level of all measures).

2. $u_i(x_j)$ is a conditional utility function of x_i normalized by $u_i(x_i^0) = 0$ and $u_j(x_i^*) = 1$.

3. The scaling constants can be evaluated by: $k_{123...n} = 1 -$

$$\sum_j u\ (x_i^0 x_i^*) + \ldots + (-1)^{n-2} \sum_{i,j>1} u(x_i^* , x_j^*, x_{ij}^0) + (-1)^{n-1} \sum_i u(x_i^* , x_i^0)$$

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APPENDIX D. PEREGRINE MODEL

The basic PEREGRINE model is multiplicative. That is, if "A" is the availability term, "M" the mission effectiveness term, and "S" the survivability term, the overall system potential <u>P=A*M*S.</u> Consider two hypothetical aircraft. One has outstanding availability and mission effectiveness scores but has terrible survivability while the other is "good but not great" in all three areas. Suppose A, M, and S are scaled from 1 to 10. Our first aircraft might rate 9-9-1 while our second rates 6-6-6. An additive model would score the two aircraft as 19 versus 18, indicating that the first aircraft by virtue of its very high availability and mission effectiveness is slightly superior to the "good but not great" aircraft. This despite the fact that it is going to get shot out of the sky any time it faces a capable air defense system. The multiplicative model would score the two planes as 81 for the first versus 216 for the second, indicating that the second aircraft is much better since it has no crippling weaknesses. This is far more supportable on both intuitive grounds and by historical examples.

The "A", "M", and "S" factors each are composed of sub-terms and these may combine additively, multiplicatively, or in some other fashion depending on the relationship between the factors involved. For example, the ability of one aircraft to shoot another down will depend on (among other factors) the first aircraft's ability to detect the target, to maneuver into shooting position, and to hit the target with its weapons. This is best expressed by a multiplicative relation between these factors since an inability to do any one of them will prevent the aircraft from hitting the target. But the effectiveness of the aircraft's radar guided missiles (for use at long range) is independent of the

effectiveness of its infrared missiles (for use in a short range "dog fight"). Even if it had zero capability to use one of these weapons types, it might have great effectiveness with the other. Thus multiplying a short-range missile factor by a long-range factor to compute an overall value for the aircraft's weapons suite would be inaccurate. Some other method of combining the factors would be more realistic.

Though the general purpose of PEREGRINE is to provide an overall measure of system potential for fighter aircraft in different missions, that potential will be not just mission but scenario dependent. For example, if two aircraft are being compared in the same mission and one has adequate survivability and very high lethality while the other reverses those characteristics, the relative value of the two will depend greatly on enemy defenses. But even the "adequate" survivability might suffice if the aircraft is supported by advanced fighters and specialized defense suppression aircraft. No static model can capture all these dynamics but PEREGRINE attempts to approximate them.

APPENDIX E. LDW RESULTS IN EXCEL

INDIVIDUAL WEAPON SYSTEM POTENTIAL

ADGUSTED AIRCRAFT POTENTIAL	UTILITIE S

TYPE	**YEAR** AAP					
	2000	**2001**	**2002**	**2003**	**2004**	**2005**
MiG -29S	0.37	0.358	0.347	0.337	0.328	0.32
MiG -29MD	0.506	0.488	0.471	0.457	0.443	0.431
MiG-29SMT	0.712	0.687	0.665	0.645	0.626	0.61

LDW FORCE POTENTIAL FP = N1 *AAP1 + N2 * AAP2

TYPE		**YEAR**					
		2000	**2001**	**2002**	**2003**	**2004**	**2005**
MiG -29S		16.65	19.0098	21.2364	23.3541	25.3872	27.36
MiG -29MD		16.65	18.06	19.335	20.565	19.935	19.395
MiG-29SMT		16.65	17.755	18.795	19.785	19.23	18.75

INVENTORY LEVEL

TYPE	2000	2001	2002	2003	2004	2005
MiG -29S	90	90	90	90	90	90
MiG -29MD	0	30	60	90	90	90
MiG-29SMT	0	10	20	30	30	30

PILOT'S PROFICIENCY

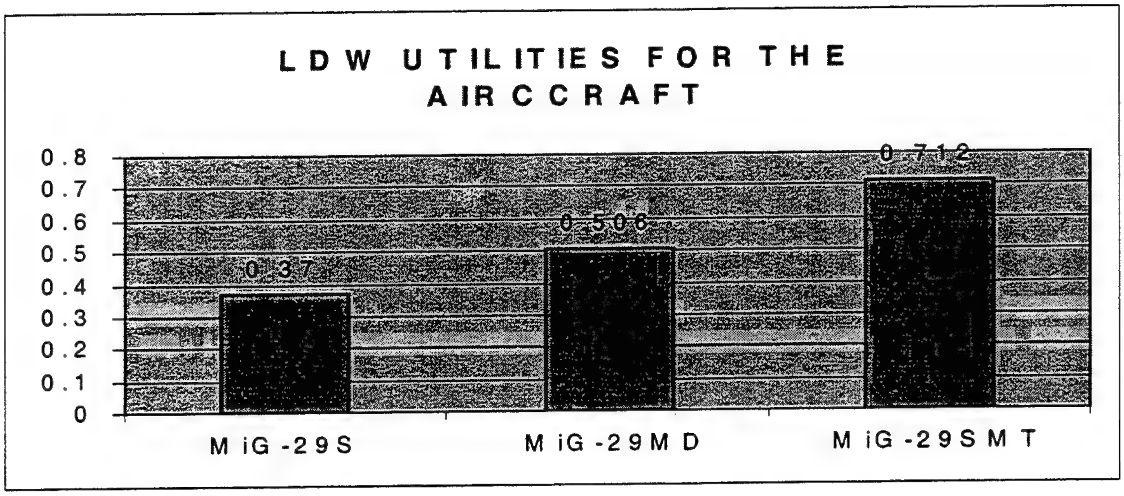
TYPE	2000	2001	2002	2003	2004	2005
MiG -29S	0.5	0.59	0.68	0.77	0.86	0.95
MiG -29MD	0.5	0.5	0.5	0.5	0.5	0.5
MiG-29SMT	0.5	0.5	0.5	0.5	0.5	0.5

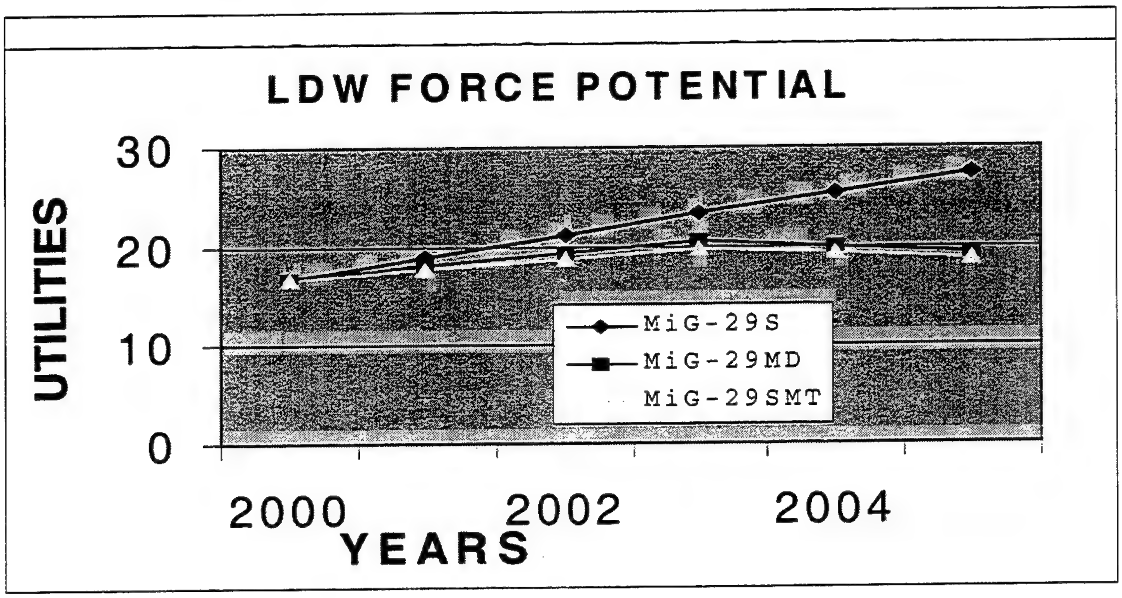
INVENTORY LEVEL

TYPE	2000	2001	2002	2003	2004	2005
MiG -29S	90	90	90	90	90	90
MiG -29MD	0	30	60	90	90	90
MiG-29SMT	0	10	20	30	30	30

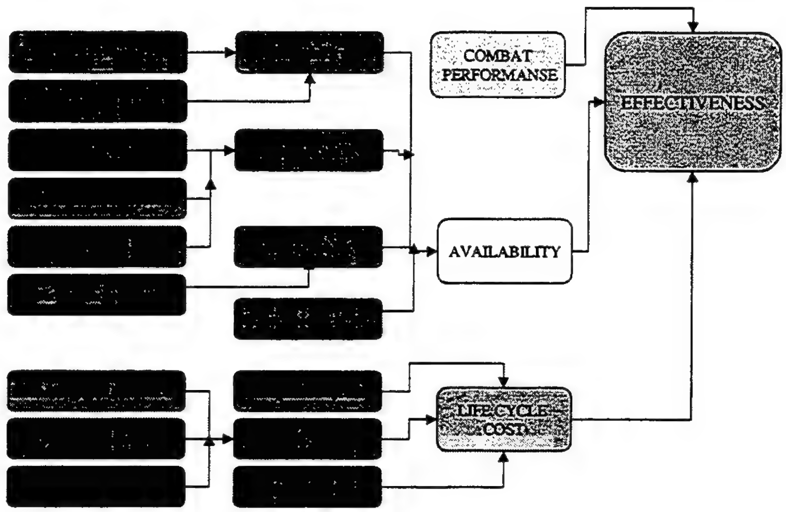
PILOT'S PROFICIENCY

TYPE	2000	2001	2002	2003	2004	2005
MiG -29S	0.5	0.59	0.68	0.77	0.86	0.95
MiG -29MD	0.5	0.5	0.5	0.5	0.5	0.5
MiG-29SMT	0.5	0.5	0.5	0.5	0.5	0.5


LDW UTILITIES FOR THE AIRCCRAFT
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.37
0.506
0.712
MiG-29S
MiG-29MD
MiG-29SMT


LDW FORCE POTENTIAL
UTILITIES
30
20
10
0
MiG-29S
MiG-29MD
MiG-29SMT
2000
2002
2004
YEARS

APPENDIX F. GRIPPEN CONCEPT OF AIRCRAFT EFFICIENCY



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APPENDIX G. DECISION-SUPPORT AND ACCOUNTING SOFTWARE EVALUATION TOOLS

EXPERT CHOICE. Expert Choice, Inc. offers two main products for sale, ECPro (for use by individual decision makers) and TeamEC (a group decision-making tool). Both products are for Windows and are based on the analytic hierarchy process (AHP). The AHP is a decision tool that is for use with decisions involving multiple attributes or criteria and multiple alternative solutions. ***www.expertchoice.com***

LOGICAL DECISIONS FOR WINDOWS. Logical Decisions for Windows (LDW) is a decision-support software tool that uses both the AHP and other multiple variable decision approaches to help decision makers make choices in complex problem situations. Like Expert Choice, LDW evaluates multiple attributes and multiple alternatives. The software can be tailored to a variety of decision contexts, such as the accounting software selection decision. ***www.logicaldecisions.com***

REQUIREMENTS ANALYST. Computer Training Services, Inc., has sold Requirements Analyst for many years. The software is regularly updated with new data about accounting software products. Decision makers supply information about the software features they either need or would like to have, and Requirements Analyst produces a list of the features associated with the optimal accounting software choice. ***ww.ctsguides.com***

SOFTWARE COMPARE. The home page address for Practitioners Publishing Company, vendors for this product, is ***www.ppcinfo.com***. Practitioners Publishing Company also sells a manual, Guide to Installing Microcomputer Accounting Systems, at this site.

THE ACCOUNTING LIBRARY. The Accounting Library (TAL) is a software tool designed specifically for the accounting software selection decision. Software vendors furnish data about their software features to the program's developer. TAL users supply data about those software features that are of particular importance. The software includes more than 100 software programs and more than 1,500 factors or software features. There are several versions of the software available at ***www.excelco.com.***

ACCOUNTING/FINANCIAL MANAGEMENT SOFTWARE-RELATED INTERNET SITES

www.accountingdirecdtory.com This site includes a directory of accounting software companies and other resources for information about accounting systems. From the site, you may access a consulting service, Accountsoft, that chooses your accounting software solution for a fee.

www.acctg2000.com A website that offers assistance in selecting the best accounting software package for your business. The site includes a list of accounting software publishers' names and sources of software support. There are links to a variety of other sites, such as educational/training sources, that can also provide you with help.

www.cpaonline.com The site includes news items related to technology that are likely to be of interest to accountants. The site also has links to a seminar series offering guidance in accounting software selection (Business and Accounting Software Update), a summary of accounting software packages, and a list of accounting software consultants in your business location.

www.ctsguides.com This is the home page for Computer Training Services, a Rockville, Md., company that sells products and services for consultants and managers to

use in selecting accounting software. The company sells software guides for special industries in addition to their premier product, The Requirements Analyst. The site also includes advice about the software selection process from needs analysis to implementation.

www.excelco.com The site is an accounting system selector that advertises The Accounting Library, You can buy all versions of The Accounting Library at this site or purchase consulting services that rely on it.

www.fsforum.com This site is a not-for-profit site where financial systems professionals exchange information in discussion groups related to their interests. The site includes resources such as a free software search service, vendor links, a resource library with articles about financial systems, and Y2K resources.

www.k2e.com/ac/accountingsoftware.htm A comprehensive Web source with information about accounting software for accountants and consultants. The site, developed by K2 Enterprises, a company specializing in offering accounting system selection support, includes information on accounting software packages, software evaluations, links to software vendors, manual and book resources available, and information on software selection seminars.

www.mamag.com/strategicfinance/vendors.htm The online listing of software vendors from Strategic Finance.

www.softwarenews.net/buyers/account.htm A software news service for accounting software buyers containing links to software vendors.

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